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Geoheritage and geoconservation – history, definition, scope and scale

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Abstract

Geoheritage and geoconservation are concerned with the preservation of Earth Science features, and are important endeavours globally, as reflected in various international and intra-national bodies set up for conservation, with agreements, conventions, and inter-governmental initiatives. Historically, the United Kingdom is considered the birthplace of the discipline of Geology, and with its history and its leadership role in the preservation of geological sites, it is also the birthplace of geoheritage and geoconservation; both endeavours are integral components of education, tourism, planning and environmental management. In addition, in Pan-Europe, and globally under the World Heritage Convention, inventory-based geoconservation has been adopted as a whole-of-government approach. Australia presents an internationally contrasting, and a nationally internally diverse history in the arena of geoconservation. Western Australia, for instance, generally lags the world trend in practicing geoconservation, while Tasmania is a leader in the arena of geoconservation. For this reason, an objective of this paper is to raise the consciousness of Western Australian scientists, planners, and land managers, who are outside the field of geology, to the issues of geoheritage and geoconservation.

Geoheritage encompasses global, national, state-wide, and local features of geology, at all scales that are intrinsically important sites or culturally important sites offering information or insights into the evolution of the Earth; or into the history of science, or that can be used for research, teaching, or reference. As geoheritage focuses on features that are geological, the scope and scale of what constitutes Geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, palaeontologic, geomorphic, pedologic, and hydrologic attributes, needs to be defined – from there, all that is encompassed by this discipline will be involved in geoheritage, and potentially, geoconservation. Geoconservation is the preservation of Earth Science features for purposes of heritage, science, or education.

While globally, and to some extent in Australia, there has been identification of sites of geoheritage importance, and development of inventory-based selection of such sites, currently there are no definitions and no framework that addresses the full breadth and scope of what constitutes geoheritage, nor adequate treatment of the matter of scale, both of which are important to identifying sites of significance. Geoconservation should encompass all important geological features from the regional scale to the individual crystal. The various scales useful for dealing with sites of geoheritage significance include regional, large, medium, small, fine, and very fine scales. While significance is noted in many works dealing with geoconservation, to date the various levels of significance, from international to local, have not been adequately addressed or defined. The level of importance attributed to a given feature of geoheritage significance is related to how frequent or common is the feature within a scale of reference, and/or how important is the feature to a given culture. Five levels of significance are recognised in this paper: International, National, State-wide, Regional, and Local.

Keywords: geoheritage, geoconservation, geodiversity, scale, significance

Introduction

Geoheritage and geoconservation are notions concerned with the preservation of Earth Science features, such as landforms, natural and artificial exposures of rocks, and sites where geological features can be examined. In this paper, geoheritage is synonymous to the idea of "Earth Heritage" of Doyle *et al.* (1994). Geoheritage focuses on the diversity of minerals, rocks and fossils, and petrogenetic features that indicate the origin and/or alteration of minerals, rocks and fossils. It also includes landforms and other geomorphological features that illustrate the effects of present and past effects of climate and Earth forces (McBriar 1995). Geoconservation derives from geoheritage, in that it deals with the conservation of Earth Science features. Globally, it has become important because it has been recognised that Earth systems have a story to tell, and that they are linked to the ongoing history of human development, providing the resources for development, and a sense of place, with historical, cultural, aesthetic, and religious values. In addition, Earth systems are the foundation of all ecological processes and part of the heritage of our sciences (Torfason 2001).

Although geoconservation is an arm of conservation, *sensu lato*, the focus of conservation to date has been concerned primarily with preservation of biota, particularly rare and endangered species, and the preservation of "communities" (Wyatt & Moss 1990; Blandin 1992; Gibson *et al.* 1994; Withers & Horwitz 1996). Conservation, however, should be concerned with more than preservation of biodiversity (Semeniuk 1997); it should embrace the range of natural history features such as 1. purely biological phenomena of scientific and heritage value, such as rare and endangered species, or representative communities, to "biodiversity" (Soule & Wilcox 1980; McNelly *et al.* 1990); 2. features combining biota and geology, geomorphology, pedology and hydrology – essentially linking biodiversity with geodiversity (Duff 1994; Hopkins 1994; Semeniuk 1997); and 3. purely physical (*i.e.*, non-biological) aspects of scientific and heritage value, such as unusual or representative rock and landscape formations (Creaser 1994; Markovics 1994). It is in this latter arena of conservation, or geoconservation, that this paper is oriented.

In a history-of-science context, both geoheritage and geoconservation, in their current form in terms of scope and objectives, are relatively newly conceived endeavours that have gained momentum only in recent years, *i.e.*, the latter part of the 20th Century in its current form in terms of scope and objectives (Gray 2004). It has come to be recognised that embedded in the materials and the surface of our globe is the story of the Earth, and if destroyed, this *archive* (or *geoarchive*) is lost to current and future generations with a loss of the core data of the already discovered information *and as yet undiscovered information*. For this reason, in recent decades, globally, there has been a drive to preserve the heritage of the Earth (what we term in this paper "intrinsically significant sites of geoheritage"), and to preserve the history of science as embodied in some classic locations (what we term in this paper "culturally significant sites of geoheritage"). Although, reserves and protected areas, including some of geoheritage significance, have been in place for centuries in countries such as the United Kingdom, Germany, and America, in Australia defined legislative frameworks to conserve and manage sites of geoheritage significance have only become the focus of attention during the past 10 years. Also, in Australia, until recently, other than places where landscapes, geological formations or physical features are of outstanding scientific importance or "scenic grandeur" (*e.g.*, the Blue Mountains in NSW, the Breadknife in the Warrumbungle Ranges, NSW, Uluru in Central Australia, the Twelve Apostles along coastal Victoria, mound springs in South Australia), there has been limited Federal legislation (Heritage Amendment Act 2003) to conserve and manage sites of geoheritage significance. While there are sites of geological significance in Australia, preserved in National Parks, and World Heritage sites, conservation of Australia's geoheritage is still in its development stage, and as such, statutory processes that incorporate the conservation of sites of geoheritage significance are still in their infancy (Sharples 2002).

Moreover, specifically in Western Australia, while there have been a number of initiatives to identify sites of geological significance through the endeavours of the National Trust in Western Australia and the Geological Society of Australia Inc. (*e.g.*, Lemmon *et al.* 1979; Carter; 1987) and others (Halligan 1994; Semeniuk 1998), there is no State legislation, nor any formal systematic process for the identification, conservation and management of sites of geoheritage significance at the regional or local planning level (Anon 2004a). To date, apart from selected sites such as those identified by Lemmon *et al.* (1979), Carter (1987), Halligan (1994) and Semeniuk (1998), meteorite impacts (Australian Heritage Commission 1978; Bevan & McNamara 1993), or Precambrian fossils (McNamara 1997), the conservation of sites of geoheritage significance generally has occurred inadvertently only as a result of processes when the site is considered to have exceptional aesthetic or tourism values, or by default, when significant vegetation assemblages occur as a result of the geology, landform, and soils (Watson 1997). Identification of such places of heritage significance on an *ad hoc* basis in Western Australia currently is undertaken by the Geological Survey of Western Australia (within the Department of Industry, Tourism and Resources), the Department of Environment and Conservation (formerly the Department of Conservation and Land Management) who, as at 2006, formally have no geologists on staff, the former National Trust of Western Australia (prior to the enactment of the Environment Protection Biodiversity Conservation Act amendment in 2003 to include heritage) who used consultant geologists, or those of the Geological Survey of Western Australia, the Western Australia Heritage Council (under the Western Australian Government Heritage Icons: Connecting A Community initiative), who use a panel of heritage experts – who may not be geologists. That is, geoconservation in Western Australia is undertaken mostly by geologists also responsible for resource development, or by agencies and organisations without formal skills in the Earth Sciences.

There have been some recent initiatives and legislation in the arena of geoheritage and geoconservation (note that the various Legislation, Acts, State Agreements, and Conventions referred to in this paper are listed in Appendix 1); these include: 1. the Memorandum of Understanding between Australia and UNESCO on cooperation concerning World Heritage in the Asia-Pacific region (UNESCO 2002); 2. amendments to the Environment Protection and Biodiversity Conservation Act 1999 (Appendix 1) to include 'national heritage' as a new matter of National Environmental Significance and to protect listed places to the fullest extent under the Constitution; and 3. the 2002 Memorandum of Understanding between the Commonwealth and the State of Western Australia where Commonwealth and State Heritage Ministers (and relevant Environment Ministers) have agreed to develop a co-operative national heritage places strategy which firstly sets out the roles and responsibilities of the Commonwealth and the States (Memorandum Of Understanding – Appendix 1), secondly, identifies criteria, standards and guidelines for the protection of heritage by each level of government, and thirdly, provides for the establishment of a list of places of national heritage significance (Department of

Environment & Heritage 1997). The process of assessing and assigning an area or feature for conservation, *i.e.*, why a site should be selected and preserved, involves scientific assessments, value judgements, and Government policies. In the light of there being no such State legislative mechanism or policy framework to identify and assess areas of geoheritage significance in Western Australia it is important to define what constitutes geoheritage and geoconservation.

In this paper we explore some of the history behind geoheritage, define and discuss terms that have evolved in recent times in relation to the ideas embodied in geoheritage, geoconservation, geodiversity, describe and discuss the issue of scale in dealing with sites of geoheritage significance, describe and discuss the levels of significance that might be applied to sites of geoheritage significance, and provides some examples of sites of significance in Western Australia. We will also define what is encompassed by geoheritage to include all matters studied in Earth Science, from mountain ranges to crystals, and from solid rocks, including ice masses, to hydrological systems and their hydrochemical products such as precipitates and karst. This paper is conceived as the first of a series dealing with the issues of geoheritage and geoconservation for Western Australia.

Brief history of geoheritage and origins of geoconservation

The international literature shows that geoheritage, focused on geology and geomorphology, globally, is now important for local cultural reasons, natural resource management, land management, research, education, and tourism (Brocx 2007). As a result, there are various international and intra-national bodies set up for geoconservation, with agreements, conventions, and inter-governmental initiatives. A major outcome of this international collaboration is that there are now various global to local inventory-based classification systems for identifying and listing sites of geoheritage significance. The international literature characterises geoheritage as primarily relating to sites of mineral or fossil locations, type sections, classic locations that illustrate Earth history, and locations where Earth processes are operating today, and locally with particular emphasis on classic sites where some principles of geology were first crystallised (*e.g.*, the site of Hutton's unconformity, or the site of Lapworth's mylonite in the Moine Thrust). While pursuit of geoconservation has resulted in the preservation of sites of geoheritage significance for science and education, and an apparent exclusion of such sites from further developments, an additional, unexpected outcome from geoconservation has been social and economic benefits – factors that have implications for the future application of geoconservation principles in Australia.

The United Kingdom is considered to be the birthplace of the discipline of modern Geology. Reconstruction of the Earth's history through its landform, rocks and fossils is said to begin with the early work of James Hutton (1726–1797), William Smith (1769–1839), and Charles Lyell (1797–1875). Hutton's idea that the history of rocks occurs in cycles, together with Smith's discovery of the layering of sediments across their geographic extent, is taken to mark the start of a period of geological enlightenment. Thereafter, many geologists such as Lyell, Smith, Murchison, and Sedgewick, amongst others, set in place the foundations of stratigraphy and palaeontology, built on an understanding of geology in the field in site-specific locations (Hallam 1989). Consequently, many locations, particularly in the United Kingdom, assumed significance as scientists identified type locations and classic sites based on an appreciation of the significance of the Earth's crust and the landscape as a basis to reconstruct the Earth's development and its causal processes.

The United Kingdom is also considered to be the birthplace of geoheritage and systematic inventory-based geoconservation, which is now an integral component of its education, tourism, planning and management (Anon 1990a). One factor underlying this was the recognition that many geological features in the United Kingdom either are type examples that illustrate geological principles that are globally relevant (e.g., Hutton's unconformity), or that are sites where geological principles were conceived and espoused for the first time. However, also important have been professional geoscientists, forming government and non-government organisations, that have been prime movers in geoconservation in the United Kingdom, and drawing a link between geodiversity and biodiversity (Duff 1994; Semeniuk 1997; Brocx & Semeniuk, unpublished MS). The significance of geoconservation in the United Kingdom is demonstrated by the enactment of the Country Right of Way Act, which effectively placed sites of international and national importance outside the hands of ownership, and into the realm of national heritage, and is recognised as being a major achievement in protection and management of sites of geoheritage significance (Prosser & Hughes 2001). Many of the principles of geoconservation developed in the United Kingdom have been exported and adopted globally, particularly the inventory-based classification system and listing of sites of geoheritage significance (Wimbledon *et al.* 1995).

Australia presents an internationally contrasting and a nationally internally diverse history in regards to geoconservation. On one hand, there exist various frameworks, working recommendations, and strategies for geoconservation (for review, see Brocx 2007), with Australia being a signatory to a number of global conventions, and having listed a number of globally important sites. On the other hand, nationally, as a generalisation, Australia's approach to its geology is resource-exploitative, rather than conservation-oriented, although this aspect is variable from State to State (Brocx 2007). Many of the major issues within Australia have arisen as a result of bioconservation and geoconservation conflicting with the mineral and energy industries (O'Connor 1991; Pouliquen-Young 1997). Joyce (1994), for instance, cites a series of articles and letters published by geologists in The Australian Geologist wherein support, debate, opposition and controversy followed the Geological Society of Australia's involvement in geological heritage matters, and in its nominating geological sites for World Heritage listing. In Australia, the major sources of wealth required to sustain population growth, infrastructure and essential services are derived from exploitation of minerals and energy

(Horne 1964; Duncan 1977; Alexander 1988; Rich & Young 1988; Collins 1991; Gould 1991; O'Connor 1991; Davis 1992; Tighe 1992; van Acker & Eddy 1992; Walker 1992; Lawrence 1994; Brocx 2007), though Willett (2002), while accepting that mineral wealth is "engine of economic growth" in Australia, argues that there has been a shift in the attitude of the mining sector towards sustainable development as a result of negative public opinion, amongst other issues. However, contrary to the notion of being able to manage exploitation of Earth resources for sustainable economic development (Willett 2002), the extraction of minerals, other Earth resources., and fossil fuels is not renewable, and if there are sites of geological significance in the target zones, political decisions have to be made (or have been made) whether to exploit the resource or to undertake geoconservation. A corollary of fact that minerals and energy drive the Australian economy is that Australia, and specifically Western Australia, generally lags behind the global trend in the practice of geoconservation.

This is not to say, or imply, that there have not been any geoconservation initiatives in Australia. Over the decades work undertaken by various individuals and organisations towards the goal of recognising sites of geoheritage significance and geological monuments and towards that of geoconservation (McBriar & Hasenohr 1994). [Note that in this paper sites of geoheritage significance are equivalent to sites of geological heritage, to sites of geological significance and to geological monuments of other authors, though geological monuments tend to be viewed as sites that have some significant import to the geological community]. Some of these undertakings were through funding by the Australian Heritage Commission with the support of the Geological Society of Australia Inc. to investigate issues of geoconservation in all States (*e.g.*, Joyce & King 1980; Mitchell *et al.* 2000; Davey & White 1984; Cochrane & Joyce 1986; Dixon *et al.* 1997; Rosengren & White 1997; Joyce 2003). Joyce (1994a) outlines the history of geoconservation that has taken place since at least 1960, when the first Divisional Subcommittees of the Geological Society of Australia began identifying geological monuments, and Cooper & Branagan (1994) compile the work of several authors who describe the work towards recognition of geological monuments in the Northern Territory, South Australia, and Tasmania. Some of the work in recognising sites of geoheritage significance was undertaken as part of the assessment of natural values of regions as part of the Regional Forest Agreements between the Commonwealth and the States (*e.g.*, Osborne *et al.* 1998; Cook *et al.* 1998; Semeniuk 1998; Anon 1999a).

Thus, progress towards geoconservation in Australia moved forward: at one extreme, through the dedicated work of individuals, *e.g.*, the establishment of the Arkaroola-Mt Painter geological province in the northern Flinders Ranges, as a privately conserved and managed geological area (Sprigg 1984), and at the other, through the work of the Geological Society of Australia Inc via its State Divisions, and through State governments that acted as instrumentalities in identifying and protecting sites of geological significance. South Australia, Victoria, and Tasmania stand as examples of the latter procedures (McBriar & Mooney 1977; Eastoe 1979; Joyce & King 1980; Sharples 1993; Dixon 1996; Dixon *et al.* 1997). In South Australia, for instance, the South Australian Department of Mines and Energy in conjunction with the National Parks and Wildlife Service reserved Wilpena Pound and its surrounds, established the "Corridors through time Geological Trail" through Brachina Gorge (Selby 1990), and protected Hallett Cove. By 2003, South Australia had recognised 433 geological monuments (Anon 2003). In Victoria, White *et al.* (2003) provide examples of sites they recognise as either of international, national, State, or regional significance, sites that had been recognised earlier in the work of Joyce & King (1980), Rosengren & White (1997), amongst others, but also point out that there are threats to these sites, as their listing as significant does not afford them adequate protection.

As a result, Australia-wide, there are many sites considered to be geological monuments, or sites of geological significance, though this does not ensure their protection. However, many of the sites of geological significance in Australia nation-wide reside in National Parks, World Heritage areas, or are locations specifically dedicated to the conservation of geological values, or have been inscribed as National Parks specifically for their landscape or geology (Australian Academy of Science 1968), or are locations that have had geological features as part of their criteria for inscription as World Heritage sites, and this is a major factor in the protection of sites of geological significance. These include Gosses Bluff meteorite impact crater in the Northern Territory, the Wolfe Creek meteorite impact crater in Western Australia, Purnululu (the Bungle Bungles) in Western Australia, the Gogo Fish fossil site in the Kimberleys, Western Australia, Geikie Gorge National Park in Western Australia, Windjana Gorge National Park in Western Australia, the Ediacara Fauna site in the Flinders Ranges, South Australia, Undara Volcanic National Park in Queensland, the Chillagoe Limestone Karst area in Queensland, Hallett Cove in South Australia, amongst others.

In this context, Western Australia also has contributed to the national inventory of sites of geological significance and geological monuments (Lemmon *et al.* 1979; Carter 1987; Semeniuk 1998), and currently, the Geological Survey of Western Australia maintains a Register of sites of geological significance, termed a "State geoheritage site", based on Lemmon *et al.* (1979) and Carter (1987). Assessment of the significance of a given site in Western Australia is based on criteria developed by the Heritage Committee of the Geological Society of Australia Inc. and by the Australian Heritage Commission, which include geological type, age, use, representative or outstanding nature, rarity, and current condition (Conservation & Land Management 2005). Recognition of the need to identify and protect such sites (termed geological sites) also was embodied earlier in the recent past in work of the Conservation Through Reserves Committee (Conservation Through Reserves Committee 1974, 1977). A brief outline of the objectives, various perceptions, problems and conflicts in the arena of conservation with regard to the Environmental Protection Authority and the unfolding of the work of Conservation Through Reserves Committee towards protection of areas because of their plants, animals, landscape, and geology is provided in Hughes (1991).

However, while there has been a recognition of the importance of features of geological heritage significance Australia-wide, there has been no systematic inventory-based geological survey as has been undertaken in the United Kingdom, and elsewhere in the world, and addressing the scale and scope of geoconservation as presented in this paper. Also, recognition of sites of significance in Australia has not always led to their protection. Sanders (2000) commented that the conservation movement is of the view that Australia's laws in relation to the protection of geological sites are weak and the Geological Society of Australia should become a proactive advocate toward the strengthening of laws to protect sites. In Western Australia, for instance, apart from sites that are captured by National Park, National Heritage and World Heritage criteria, and inscribed mainly under Commonwealth powers, the majority of geological sites recommended by Lemmon *et al.* (1979), Carter (1987) and Semeniuk (1998) remain unsecured.

Similarly, following their systematic description of the various landforms of the Quindalup Dunes, at various scales, along the full climatic extent of this coastal system from Geographe Bay to Dongara, Semeniuk *et al.* (1989) concluded that there were an inadequate number of reserves capturing the full variability of dune landforms in this coastal system. While the Leschenault Peninsula (Semeniuk 1985) and part of the Becher Cuspate Foreland (Searle *et al.* 1988; C A Semeniuk 2006) are now protected in Reserves, in contrast, to date, since the work of Semeniuk *et al.* (1989), little has been achieved in securing adequate reserves in the Quindalup Dunes based on geoheritage criteria – in fact, there has been extensive modification, urbanisation, and development of these dunes (as described by Semeniuk & Semeniuk 2001).

Some overseas and Australian examples of sites of geoheritage significance

Prior to dealing with issues of scope, scale and significance in geoheritage, five areas that have already been recognised as sites of geoheritage value are described below to provide an overview of what may captured under the umbrella of geoconservation. They provide examples of the range of geological phenomena that have been recognised as constituting features of geoheritage value. The five areas are arranged in decreasing scale, and are drawn from the Grand Canyon in the United States of America, Shark Bay in Western Australia, the Precambrian Ediacara fauna of the Rawnsley Quartzite in South Australia, the Cambrian fauna in the Burgess Shale in Canada, and Jack Hills in Western Australia. Two of the locations, *viz.*, The Grand Canyon and Shark Bay, are recognised as globally significant sites, being listed as World Heritage areas, and represent features at a large scale frame of reference, but encompass a plethora of smaller scale features. The Ediacaran in fauna in the Rawnsley Quartzite in South Australia, and the Cambrian fauna in the Burgess Shale in Canada, containing an early record of diverse organised metazoan life on Earth, also are sites of international significance, albeit at smaller scales of reference. Jack Hills, a rocky low range with an uninteresting macroscopic appearance, is an exceptional site of global significance (while it is on the Interim Listing on the Register of the National Estate, *cf* Department of Environment & Heritage 2004, it has no other formal recognition as such), due to its global importance at the crystal scale.

The Grand Canyon, USA

The Grand Canyon is an internationally well known landform, and a World Heritage site, inscribed in 1979. The Canyon is part of the Colorado River, and portrays several important geomorphic and geological features (Holmes 1966; Shelton 1966). Firstly, geomorphically, it is a meandering river that has incised into a tectonically uplifted plain, the Colorado Plateau. At the end of the Cretaceous, the Plateau was a lowland plain and coastal plain, with an ancient meandering sluggish Colorado River. With uplift, the river incised into the plateau, matching uplift by erosion such that the meandering form was preserved. In this regard, the Grand Canyon illustrates ancestral landforms (the ancient meandering river – now an entrenched antecedent river), tectonism (to produce the Colorado Plateau), riverine erosion keeping pace with tectonism (to produce the incised meanders), and exhumation of the harder rock layers of the former Cretaceous Colorado Plain (to form the present surface of the Colorado Plateau). Secondly, the Grand Canyon exposes a classic sequence of stratigraphy and stratigraphic relationships. At the base, there are Precambrian metamorphic and igneous rocks (granites and schists), with folded, faulted and deformed layered metamorphic rocks intruded by granites, overlain unconformably by lower Palaeozoic sedimentary sequences (*viz.*, the Cambrian), and then by upper Palaeozoic sequences (Carboniferous and Permian). The cliff exposure illustrates an angular unconformity between Precambrian and Cambrian rocks, and a concordant unconformity between lower and upper Palaeozoic rocks. The region thus is a globally important classroom for the aspects of megascale geomorphology and tectonism, local stratigraphy and stratigraphic relationships, and modern riverine processes.

Shark Bay, Western Australia

Shark Bay also is another internationally well-known area, and a World Heritage site inscribed in 1991 because of its marine and terrestrial environments, and its geology, geomorphology, and carbonate sedimentology. It is one of the few places in the world that satisfy all four natural criteria for listing, *i.e.*, an area showing major stages of the world's evolutionary history, showing ongoing geological and biological processes, natural beauty, and containing threatened species and important and significant habitats for *in situ* conservation of biological diversity. From a geologic and geomorphic perspective, the region hosts Quaternary coastal, near-coastal, and marine landforms, and exhibits a wealth of geological, geomorphic, sedimentologic, and tectonic features (Logan & Cebulski 1970; Playford 1990). At the megascale, there is the Yaringa Province on the mainland to the east (a plateau of Mesozoic and Tertiary limestones), the central Peron Peninsula (of orange and red sand that separates the two main basins of Shark Bay), and the western digitate peninsula of Edel Land (composed of mobile parabolic dunes and lithified

Pleistocene aeolianite limestone). The array of these landforms is due to climatic, eustatic, and tectonic factors (Logan *et al.* 1970). At smaller frames of reference, there is an abundance of coastal landforms determined by Pleistocene ancestral forms (*e.g.*, digitate inlets along the eastern coast of Edel Land resulting from inundation of parabolic dunes), or by Holocene coastal processes (*e.g.*, beachridges, or seagrass bank platforms and sills), and there are globally significant sedimentary products (such as the Hamelin Coquina shell beds, oolitic sand banks, stromatolites, gypsum crystal beds, and cemented crusts). The region is a globally important classroom for megascale coastal geomorphology, arid zone sedimentation, the interplay of sedimentation and coastal geomorphology with Quaternary tectonics, and smaller features such as stromatolites and gypsum crystal beds.

The Ediacara fauna in the Rawnsley Quartzite, South Australia

The Rawnsley Quartzite (formerly the Pound Sandstone) occurs in the Ediacara Hills in the Flinders Ranges, north of Adelaide in South Australia (Jenkins 1975; Drexel *et al.* 1993). At the site of the exposure of the Ediacara fauna, the Rawnsley Quartzite occurs in a semi-arid landscape that is not remarkably different from the geomorphology, geological structure and lithology elsewhere in the region (Drexel *et al.* 1993), and from a perspective of the style of outcrop, local geomorphology, geological structure, and the lithology itself, the location may not be considered to be of national or even regional significance. The importance of the site resides at the bedding scale: while complex metazoan life on Earth, gleaned from the geological record globally has been accepted to have evolved at *circa* 550 Ma, which defines the Cambrian/Precambrian boundary, the Rawnsley Quartzite contains evidence of metazoan life in Precambrian rocks (Glaessner 1966). It is the best preserved record of the earliest metazoan life on Earth, and as such is of global importance.

The Cambrian fauna in the Burgess Shale, Canada

The Burgess Shale occurs in the Rocky Mountains of British Columbia in Canada, in the Yoho National Park. It is Middle Cambrian in age and contains a remarkably diverse and well preserved metazoan fauna (Whittington 1985). So far, about 150 species belonging to 120 genera have been described (Whittington 1980), but many of the animals are difficult to assign to present phyla. According to Gould (1989), the fauna "*contains the remains of some fifteen to twenty organisms so different one from the other, and so unlike anything now living, that each ought to rank as a separate phylum*", thus suggesting that there were more numerous phyla in the Middle Cambrian than today, many of which are now extinct. However, other authors have challenged the conclusions of Gould (1989), and suggest that while the fauna is diverse, a number of the taxa that were thought to belong to unique (and now extinct) phyla can be assigned mostly to existing phyla, albeit as distinct families and orders (Morris 1998). Nonetheless, most authors agree that the fossil occurrence provides an important and unique palaeontological window into metazoan life of the Cambrian. At the site of the exposure of the fauna, the Burgess Shale occurs in a boreal mountainous landscape that, from a perspective of the style of outcrop, local geomorphology, geological structure, and the Burgess Shale lithology itself, is not remarkably different from the geomorphology, geological structure and lithology elsewhere in the region. The importance of this site resides, as with the Ediacara fauna, at the bedding scale: while elsewhere, globally, Cambrian metazoan faunas are dominated by porifera, archeocyathids, coelenterates, bryozoans, graptolites, trilobites, and brachiopods, amongst others, belonging to phyla that mostly still exist today, the fauna of the Burgess Shale, according to Whittington (1980, 1985) and Morris (1998), records evidence of a plethora of quite different metazoan life in Middle Cambrian times, and a number of these life forms probably belonging to unique phyla, though necessarily as many as claimed by Gould (1989). It is an early record of the formerly diverse metazoan life on Earth, best preserved in this location, and of global importance.

Jack Hills, Western Australia

Jack Hills, located in the Narryer Gneiss Terrane of the northern Yilgarn Craton, Western Australia, is part of a rocky landscape set in an arid climate. The Mount Narryer Quartzite, a metaquartzite, is an important formation in this Precambrian terrane (Wilde & Pidgeon 1990). The terrain/terrane of this area is unremarkable, and relatively uninteresting at the macroscale geologically, stratigraphically, and geomorphologically. However, within the metaquartzite are polycyclic zoned zircons with a maximum age of *circa* 4.4 Ga (Wilde *et al.* 2001; Cavosie *et al.* 2004). They are, effectively, the oldest crystals in the world, and illustrate that cratonisation and sedimentary reworking of granitic cratons was well underway by 4.5 Ga ago, and that the Earth was already solid 50 million years after its formation. The geological feature of global significance in this area is at crystal scale. To emphasise the significance of this occurrence, these crystals date back to the origin of the Solar System, providing unparalleled insights into the early origin of the Earth, and essentially providing information on the petrogenesis on our planet near the age of the inception of the Solar System.

The scope of geology as a basis for geoheritage

Geoheritage and geoconservation are concerned with geology, so it is worthwhile to explore what constitutes the science of geology and hence, what may be encompassed by the umbrella of geoheritage and geoconservation.

The term geology, often used synonymously with Earth Sciences is a diverse discipline. Examined in detail, Geology and its subdisciplines, overlap with other disciplines such as Chemistry (*e.g.*, crystal chemistry and geochemistry are subdisciplines both of Geology and of Chemistry, and the study of crystal deformation and crystal lattice defects is carried out in Geology, Material Sciences, and in Engineering). We consider that all the subdisciplines of Geology to be a part of Geology *sensu stricto* where particular subdisciplines are oriented in their endeavour to the study of the Earth, even if the same subdiscipline is shared by another science. This is important, because this paper contends that the full scope of what constitutes Geology should be within the scope of what could be considered to be of heritage value, and what is considered to be of geoconservation value.

The scientific discipline of Geology involves subsidiary disciplines of igneous geology, metamorphic geology and sedimentary geology, igneous, metamorphic and sedimentary petrology, structural geology, mineralogy, palaeontology, geomorphology, pedology, hydrology and surface processes such sedimentology (see Glossary of Geology; [Bates & Jackson 1987]). This traverses a wide range of scales: at mega-regional scale it includes global tectonics, mountain building, and landscape evolution; at smaller scales, it includes Earth surface processes such as weathering, erosion and sedimentation, involving ice, water, and wind; and at microscale, it includes diagenesis, crystal defects and deformation, amongst others. Chemically they involve studies of precipitation, cementation, solution, and alteration at all scales (Wilson 1954).

For example, to illustrate the scope of what is considered to be geology, and hence geoheritage, in their description of geoheritage features of the Swan Coastal Plain in Western Australia, Semeniuk & Semeniuk (2001) identify a wide range of geological features that they considered fall under the umbrella of geoheritage; they include igneous, metamorphic and sedimentary rocks, and their relationships at all scales (*e.g.*, craton/basin relationships), mineral locations, fossil locations, pollen locations, type stratigraphic locations, along with type igneous, metamorphic or pedogenic locations, sites of importance in understanding geological processes, sites of importance geomorphologically, sites of importance pedologically, sites of importance sedimentologically/stratigraphically, sites of importance hydrologically, and sites of profound aesthetic geological importance, or of intrinsic geological value.

The science of geology has been split into two distinct streams or schools – those undertaking investigation of causal processes; and those seeking to historically reconstruct the Earth's development. These two schools were said to be separated by a "great barrier" (Wilson 1954). We term these two schools the geological processes school and the historical geological school, separating process-oriented endeavours and product-oriented endeavours. Historically each school looked at different features of the Earth, using different (though at times overlapping) techniques. These two schools of geology persist today, with one continuing to investigate causal processes such as weathering, erosion and sedimentation, and at the micro scale, studies of crystal defects and deformation, while the other, the historical geologists, working at the macro-regional scale to establish the succession of the Earth's development, studying global tectonics, mountain building and landscape evolution, *i.e.*, the product of Earth processes, and at the small scale, the history and products of diagenesis, weathering, pedogenesis, metamorphism, and crystallisation. The two approaches overlap in that information about processes is foundational to understanding and interpreting geological products.

Clearly, also, the two approaches generate two diverse conceptual categories on which to consider geoheritage. It is our contention that, in geoheritage and geoconservation, *both processes and products need to be addressed*. For instance, citing two examples where processes may be extant: the environment and medium that allow dune formation to take place, and the environment and medium whereby diagenesis, such a calcite precipitation leading to dune sand cementation, induced by hydrochemical processes takes place, need to be considered in geoconservation. That is, the environment or setting whereby specific physical and chemical processes are operating need to be identified and conserved. Coastal dune environments producing representative highly attenuated parabolic dunes oriented in the dominant wind direction, or fretted parabolic dunes (such as in the Jurien area and Quinns Rocks area, respectively, in southwestern Australia; see Semeniuk *et al.* 1989) are examples of areas exhibiting dune formation *processes*. The various Holocene environments of Shark Bay, wherein there is tidal zone cementation, anaerobic marine phreatic diagenesis, stromatolite cementation, gypsum crystal formation, and skeletal grain dissolution (Logan 1974) are examples of an area illustrating diagenetic *processes*. Equally, products of these processes (such as the dunes themselves, or specific crystal formation, cementation, or colour mottling, amongst other diagenetic products) also need to be considered in geoconservation. Thus, geoconservation can focus either on processes (and these, and their products, will be extant in the modern environments), or on products (and these will be extant in modern environments, as well as present in stratigraphic sequences, mineral and fossils deposits, and metamorphic and structural terranes).

Table 1 presents the range of subdisciplines (process and product-oriented) considered to be part of Geology, and which we contend should be considered in inventory-based assessments of geoheritage and geoconservation.

Figure 1 illustrates a selected range of geological features in Western Australia that span the scope of geological phenomena, as listed in Table 1, that would qualify to be assessed as sites of geoheritage significance (in addition to the foregoing discussion, Figure 1 will also be used in a discussion of levels of significance to be developed later in the paper).

Within Figure 1, the aerial photograph of Cape Range, viewed to the south, illustrates a large scale geological and geomorphic feature (Fig. 1A). The Range is a tectonically uplifted ridge of Cainozoic limestone (Hocking *et al.* 1987), on which has developed consequent streams. The ridge also records a continuous history of uplift during the Quaternary, reflected in terraces cut into the Quaternary limestones (van de Graaff *et al.* 1976). Yardie Creek, cut into the limestone, and with a sand bar at its mouth, is in the foreground. Ningaloo Reef is evident in the shallow water to the west. The linear dune field in the Great Sandy Desert (Veevers & Wells 1961) illustrates a desert geomorphic feature of aeolian landforms (Fig. 1B). The recurved spit of accumulated small shells of *Fragum hamelini* (the Hamelin Coquina of Logan *et al.* 1970) illustrates a coastal geomorphic and stratigraphic feature, where active Holocene sedimentation has resulted in the development of a prograded shell grit beachridge system (Fig. 1C). The buttes in the north-western Pilbara, illustrate geomorphic and geologic features (Fig. 1D),

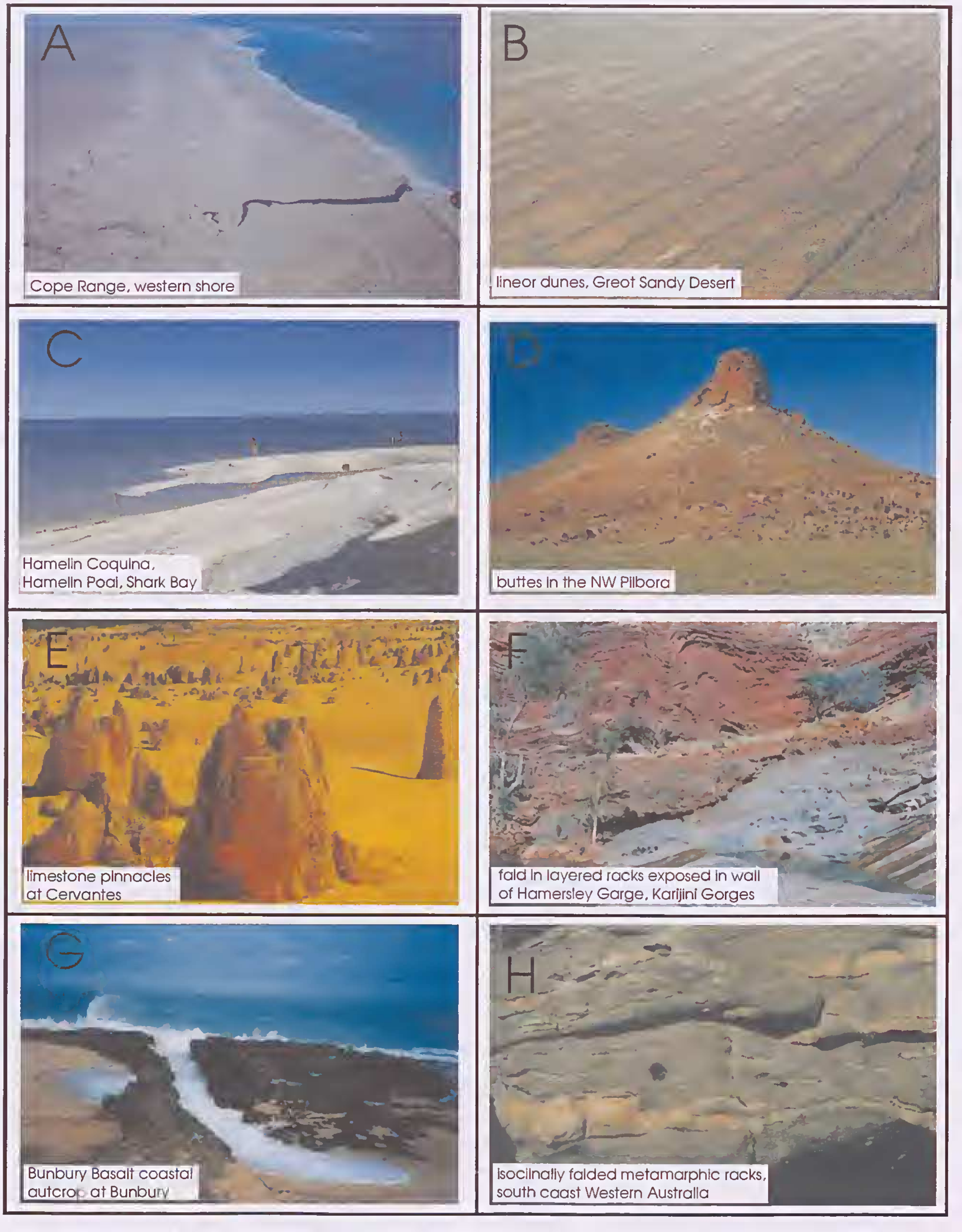

Figure 1. Some examples in Western Australia of different geologic and geomorphic features at various scales and of various geoheritage significance, arranged in decreasing scale. A. Limestone range in the Cape Range region (geologic and geomorphic features); B. linear dune field in the Great Sandy Desert (geomorphic feature); C. Hamelin Coquina in Hamelin Pool, Shark Bay (coastal geomorphic and stratigraphic features); D. Buttes in the north-western Pilbara region (geologic feature, and geomorphic feature centred on an unconformity); E. The Pinnacles at Cervantes (geologic and geomorphic features); F. A fold in layered ironstone and chert developed above a local decollement, exposed in a gorge in the Hamersley Ranges, Karijini (geologic feature); G. Outcrop of the Bunbury Basalt at the coast, south Bunbury (geologic feature, and coastal geomorphic feature); H. Isoclinally folded metamorphic rocks, exposed in coastal cliffs in southern Western Australia (geologic feature, i.e., structural and metamorphic features).

Table 1

The range of main subdisciplines and specialised subdisciplines within Geology

Main subdiscipline	Selected list of associated more specialised subdisciplines
Mineralogy	crystallography, mineral chemistry, geochemistry
Igneous geology	petrology, geochemistry, mineralogy, volcanology, geochronology
Metamorphic geology	petrology, geochemistry, mineralogy, geochronology
Sedimentary geology	petrology, geochemistry, mineralogy, stratigraphy, diagenesis, skeletal taphonomy, ichnology, geochronology
Structural geology	mechanical deformation, geomechanics, crystal deformation, geometric analyses, terrane analyses
Marine geology	marine geomorphology, stratigraphy, sedimentology, igneous geology, geochronology
Stratigraphy	sedimentary petrology, mineralogy, geochronology
Palaeontology	palaeobiology, palaeoecology, evolutionary biology, skeletal petrology, ichnology, taphonomy, mineralogy, geochronology, biostratigraphy
Sedimentology	stratigraphy, sedimentary petrology, geochemistry, mineralogy, diagenesis, ichnology, skeletal taphonomy, carbonate sedimentology, terrigenous sedimentology, evaporite sedimentology, fluid mechanics
Glaciology	ice stratigraphy, ice petrology, crystallography, crystal deformation, geochemistry, sedimentology, glacial geomorphology
Palaeoclimatology	stratigraphy, geochronology, palynology, biostratigraphy
Pedology	stratigraphy, petrology, geochemistry, mineralogy
Hydrology	stratigraphy, hydrogeology, hydrodynamics, hydrochemistry, isotope chemistry
Geomorphology	fluvial geomorphology, aeolian geomorphology, volcanogenic geomorphology, karst geomorphology, coastal geomorphology, marine geomorphology, desert geomorphology, alpine geomorphology, geomorphic processes
Surface processes	weathering, erosion, transport

where Mesozoic sedimentary deposits (the resistant capping) rest with unconformity on Precambrian granite, with the contact representing the stratigraphic interface between deposits of the Canning Basin and the Pilbara Craton. The Pinnacles at Cervantes illustrate a geological and geomorphic feature (Fig. 1E): calcrete impregnated/ cemented pipes, normally buried beneath a cover of yellow quartz sand, stand in relief above an aeolian-eroded landscape wherein the yellow sand cover has been removed. The fold in the rocks of the Brockman Iron Formation of Hamersley Group (Macleod 1966), composed of laminated ironstone and chert, illustrates a geological feature; that is of a fold formed in response to a decollement, in a zone of layer-parallel shear (Fig. 1F)). The outcrop of Bunbury Basalt at Bunbury illustrates the exposure of a valley fill of this basalt exhumed by coastal erosion (Fig. 1G). Normally, in this region, the valley fills of Bunbury Basalt lie buried below the surface (Playford *et al.* 1976). The outcrop also shows coastal geomorphic features. The folded metamorphic rock of interlayered mafic (dark coloured) and felsic (light coloured) layers, occurring in the Irwin Inlet area, southern coast of Western Australia, illustrates isoclinally folded granulite, and is a structural and metamorphic feature (Fig. 1H).

The variety of terms now associated with geoheritage and geoconservation

In the short history of the coining of the term geoheritage in the 1990s, there has already been a proliferation of related terms, and confusion associated with new and existing terms. It is useful therefore to trace the origin of the terms, and discuss the meanings ascribed to the terms geoheritage, geoconservation, and geodiversity. Each of the terms are described below as to their first use, etymological understanding of the terms (this paper), and our preferred definition of a given term. Appendix 2 provides definitions of the terms geoheritage, geoconservation, geodiversity, and other related terms, as used in the literature. A review and discussion of terms in the arena of geoconservation also is provided by Prosser (2002a, 2002b).

Geoheritage

The term geoheritage derives from the word heritage, which means something that has been transmitted from the past, or has been handed down by tradition. The term is used internationally, and in Australia, and carries a notion of the heritage of features of a geological nature. It axiomatically conveys the idea that there is something (valuable or otherwise) to inherit from the past and pass on to the future. The term geoheritage evolved from "geological heritage" (just as the term biodiversity evolved from the term biological diversity). The term "geological heritage" first makes its appearance in the First International Symposium on the Conservation of our Geological Heritage at Digne, France in 1991 (Anon 1991). The term geoheritage first makes its appearance in the literature in the Malvern International Conference, the 2nd international conference dealing with geological and landscape conservation, held in the Malvern Hills (UK) in 1993 (Joyce 1994b; O'Halloran *et al* 1994).

Between 1991 and 2006, a variety of definitions and concepts of geoheritage and related terms appeared in the literature (see Appendix 2). Generally, geoheritage is used as a descriptive term associated with the conservation of Earth features, with theoretical concepts and definitions of geoheritage still in their developmental stage (Sharples 2002).

Historically, geoheritage as a concept, (though not as a term), can be traced back to the time when knowledge was being gained from the geological discoveries made during the Industrial Revolution (Busby *et al.* 2001). As noted earlier, when geologists in the United Kingdom such as Lyell, Smith, Murchison, and Sedgewick set in place the foundations for the science of geology, stratigraphy and palaeontology, built on an understanding of geology both in the field, and on site-specific locations (Hallam 1989), many locations assumed significance as scientists identified type locations and classic sites. This was based on an appreciation of the significance of the Earth's crust and the landscape as a basis to reconstruct the Earth's development and the causal processes. These locations were called sites of Earth Heritage, and preserved as sites of special scientific significance.

The term geoheritage first appeared in the grey literature in Australia in Bradbury (1993) and Sharples (1993. 1995). Later it was used by Dixon (1996), Semeniuk (1996), the Australian Heritage Commission (1997), Semeniuk & Semeniuk (2001), Conservation & Land Management (2005), & Anon (2006).

Sharples (1995) expanded the original idea of geoheritage to include the protection of dynamic geological processes *and* geodiversity, *i.e.*, processes and products, for their inherent or intrinsic values, and argued that where geoconservation is based on aesthetic, scientific or cultural reasons it actually involves making anthropocentric value judgements with the implication that the natural environment exists only for human use. Dixon (1996) similarly rejects the notion that the natural environment exists only for human use, and raises the question of the ethics and of giving moral consideration to the natural environment for the right to exist without justification. While in principle we agree with these notions, as geoheritage leads to (active or passive) geoconservation it involves some degree of assessment and value judgement.

In this paper, we use the term geoheritage, expanded and modified from Semeniuk (1997) and Semeniuk & Semeniuk (2001), in the following manner:

Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, and hydrologic attributes, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference.

Using this definition, geoheritage covers natural features that are intrinsically important (such as the Jack Hills zircons, or the Ediacara fauna), and cultural features (such as the historically important site of the first description of an unconformity by Hutton; scenically important sites such as The Twelve Apostles along the coast of Victoria; and culturally important sites such as the Devil's Marbles in the Northern Territory. Intrinsically important sites may be globally unique, while culturally important sites may be common globally, but have a human value, acknowledging that some sites have both an historic as well as an intrinsic value. This distinction is important, in that the former may comprise globally unique sites, while the latter may be important only culturally, *e.g.*, unconformities may be common globally, and may be better examples than at Siccar Point where Hutton described them for the first time, but the location at Siccar Point represents an important historic as well as (an intrinsically) important geologic site.

Geoconservation

While geoheritage concerns the heritage of features of a geological nature, geoconservation is the action that works towards the preservation of sites of geoheritage significance. The term geoconservation was coined and began its use in the 1990s (Sharples 1995). Semeniuk (1996), and Semeniuk & Semeniuk (2001), consider geoconservation to be the conservation, or preservation of Earth Science features for purposes of heritage, science, or education. Other authors use the term in a similar manner. Etymologically, it combines the action of conservation with "geos" (the Earth), implying conservation specifically of features that are geological. Geoconservation involves the evaluation of geoheritage for the purpose of conservation and land management, leading to the protection of important sites by law.

In the international literature, geoconservation has a broader scope than is dealt with here, involving the conservation of sites of geoheritage significance (as in this paper), but also deals with and is involved with matters of environmental management, geohazards, sustainability, and natural heritage as it relates to maintaining habitats, biodiversity, and ecosystems in general. In this paper, while we accept the broader implications of the notion of geoconservation as used overseas, we focus geoconservation to the objective of preserving sites of geoheritage significance. We use the term geoconservation in the sense of Semeniuk & Semeniuk (2001), *i.e.*, preserving sites of geoheritage significance.

Geodiversity

Following the introduction of the term geoconservation for the preservation of geological features for their intrinsic, ecological and geoheritage value (Sharples 1995), the term geodiversity was coined and at one stage appeared to be replacing the term geoheritage. Further, some authors made geodiversity analogous with biodiversity (Kiernan 1990; Eberhard 1997). Given the relative success of the term biodiversity in galvanising support for conservation of the biosphere, it was anticipated that the term geodiversity would carry some of the enthusiasm for bioconservation into the realm of the geological systems (Eberhard 1997). Specifically in Australia during the mid to late 1990s, the term geodiversity began to replace the term geoheritage.

However, a number of authors have criticised the term (Joyce 1997, Vincent 2004), as it carries with it some definition and concept problems. Currently, there are two main interpretations of the meaning of term geodiversity (Sharples 2002): that developed by Earth scientists in the (Department of) Forestry, Parks and Wildlife in Tasmania (Dixon 1996, Sharples 1995, Kiernan 1995, 1997, Household *et al* 1997) and accepted by the Australian Heritage Commission (1997), and that of Joyce (1997) and Semeniuk (1997). The former consider geodiversity to be the diversity of geological features on the Earth, and essentially use the term to connote the variety of features within Geology. The latter consider geodiversity to be a site-specific or region specific denoting the natural variety of geological, geomorphological, pedological, hydrological features of a *given* area (Semeniuk 1997). This would involve geologic products at one extreme (*e.g.*, cliff faces, shorelines, sandy spits, limestone pinnacles, or river canyons), to the assemblage of products and their formative processes at the other (*e.g.*, active parabolic dunes forming under a given wind regime). As such, the former, *i.e.*, the notion of Dixon (1996), Sharples (1995), Kiernan (1995, 1997), Household *et al* (1997), and the Australian Heritage Commission (1997) is equivalent to the term geology, and the latter, *i.e.*, the notion of Joyce (1997) and Semeniuk (1997) is the geological equivalent of biodiversity.

In this paper we use the term geodiversity in the following manner (after Semeniuk 1997):

the natural variety of geological, geomorphological, pedological, hydrological features of a given area, from the purely static features (i.e., products such as shorelines, sandy spits, or limestone pinnacles, or river canyons) at one extreme, to the assemblage of products, and at the other, their formative processes (e.g., active parabolic dunes forming under a given wind regime).

We suggest that use of the term geodiversity, which etymologically means "the diversity of geological features", should to be applied only to region-specific or site-specific features. It should not be used to mean "diversity of all things geological", because the term geology is broad enough in scope and scale (as discussed above) to carry that implication.

Furthermore, the term geodiversity should not be used as a substitute for the term geoheritage (which, as noted above, means geological features that have been the transmitted from the past, or have been handed down by tradition): geodiversity connotes diversity, whereas geoheritage connotes heritage. Geoheritage encapsulates a specific concept, and the heritage portion of the word cannot be rationally substituted for by diversity.

In addition, whilst in the field of conservation the terms geoconservation and bioconservation have parallel meanings, geodiversity with biodiversity do not. That is, substituting geo for bio in the term biodiversity changes the notional meaning and scale of application of the word. These issues are discussed in more detail in Brocx & Semeniuk (unpublished MS).

We conclude that the use of geodiversity as a term meaning the diversity of geology worldwide is a surrogate term for Geology itself, and use of the term in this sense should be abandoned in favour of its meaning as reflecting a site-specific feature of geology, and being linked to biodiversity in that local or regional geodiversity underpins biodiversity (Semeniuk 1997).

Used in the sense of site-specific or region-specific diversity, the geodiversity of a site or region lends itself to measurement, once the scale of the geological components and the size of the area being measured are given (Brocx & Semeniuk unpublished MS). For example, an intensely fault-splintered terrane in a given region may be comprised of a stratigraphically diverse sequence of rocks, a palaeontologically diverse sequence of formations, and a mineralogically diverse suite of metamorphic rocks. The term geodiversity can be applied to this area, at all scales.

However, given that geodiversity (*sensu* Semeniuk 1997) can be measured, it would be erroneous to conclude that it carries with it conservation significance in the same way that biodiversity does. Low geological diversity is not more or less important than high geological diversity. For instance, a thick monotonous sequence of black limestone, spanning 10 million years, accumulating to hundreds of metres thickness may exhibit low (geo)diversity, but has a story to tell about Earth crust evolution, constancy of basin subsidence, and consistency of hydrochemistry and environment. Geologically complex situations, for example, where a variety of rock systems from various tectonic regimes have been juxtaposed together by faulting and then intruded by a granite batholith, resulting in a wide variety of rock types with a plethora of sedimentary, igneous, metamorphic, and metasomatic minerals can result in a system of high geodiversity. This type of system will have internally complex stratigraphic and structural relationships, resulting in complex hydrology and hydrochemistry, and complex landforms and soils, which in turn result in a complex response in the biota (*i.e.*, species and community biodiversity). But while such a site may be a location where there is a concentration of features useful for holistic studies in that many subdisciplines of geology can be applied to the site, and there is a wide variety of materials for reaching and research, and while it is a site where complexity itself can be researched, it is not inherently a more important site than one with less complexity.

For site-specific and region-specific assessments, to emphasise geodiversity as a basis for geoconservation, as one would emphasise biodiversity as a basis for (bio)conservation, would be placing undue emphasis on terranes that had been, for instance, tectonically derived or tectonically and structurally modified. The logical conclusion would be that the only geological systems or terranes that are worthy of geoconservation are those that have been complexly altered/modified diagenetically, metamorphically and tectonically, and the more complex the alteration the greater the geoconservation significance. We reject such a notion. Brocx & Semeniuk (unpublished MS) argue that the significance of geodiversity is its link to biodiversity.

The matter of scale in geoheritage and geoconservation

As described above, a coining of new terms and variable use of meaning of the existing terms in geoconservation, globally, and to some extent in Australia, has resulted in the need to define and redefine the breadth and scope of what constitutes geological heritage, in the recognition of sites of geoheritage importance, and in the development of inventory based selection of sites. The issue of scale, and its importance to geoheritage, however, has not been dealt with in the literature, though its principle is implicit in some of the wording in various global Conventions and Acts, and in the Australian Acts (Australian Heritage Commission 1990; Heritage Amendment Act 2003). That is, most of the progress in geoheritage and geoconservation has been scale independent. However, we consider that this matter is important to developing ideas of what is encompassed by geoheritage, and as such, the matter of scale in geoheritage needs to be addressed directly.

Scale is an important issue to consider in geoheritage and geoconservation, because sites of significance can range in size from that encompassing landscapes and geological phenomena at montane-scale, to that at the scale of a crystal. A review of the literature shows that in many locations of the world, geological sites are important because of crystal-sized phenomena, and crystal fabrics, because it is often at this scale that the story of the Earth unfolds. For instance, the snowball garnets of Vatterbotten, Sweden (Barker 1998), the orbicular structures of the Thorr Granodiorite of Donegal, Ireland (Pitcher 1993), or the zoned zircons from Jack Hills in Western Australia (Wilde *et al.* 2001) all tell important stories about the Earth: the rotation of garnets and their spiralling incorporation of surrounding layered matrix under conditions of shear, or the concentric whisker crystal growth under delicate conditions of growth, diffusion and cooling, or the zoned zircons that illustrate that the Earth was already solid 50 million years after its formation, respectively. Each of these locations represents unique and classic examples of Earth history, yet the history is embedded at the crystal scale.

At the next scale in increasing size, important geological phenomena of geoheritage significance are represented by dinosaur footprints (Geological Survey of Western Australia 1975), fossil sites such as the Precambrian Ediacara fauna in South Australia (Glaessner 1966), the Cambrian Burgess Shale fauna in Canada (Gould 1989), Hutton's classic unconformity site (Hutton 1795, cited in Dean 1992), Lapworth's mylonite site (T A Semeniuk 2003), or egg carton folds in laminated quartzite and marble (Hobbs *et al.* 1976).

Important geological and geomorphological phenomena continue to occur in increasing scale, right up to the scale of mountain ranges and major drainage basins.

In Australia, a large range of geological and geomorphological features of geoheritage significance, and criteria for their selection are described and discussed by Joyce (1995), Grimes (1995), and Kiernan (1997), amongst others. In the context of scale discussed above, these authors illustrate a wide variety of geological and geomorphological features of geoheritage significance, and from their examples it is clear that there are sites of geoheritage significance that occur at various scales.

The Australia Heritage Commission (1990) partly dealt with scale in geological/landform units by assigning three levels, as follows: large scale (*e.g.*, Central Plateau of Tasmania), medium scale (*e.g.*, Lake George, or the Glasshouse Mountains), and small scale (*e.g.*, Hallett Cove, Geikie Gorge, or Quincan Crater). Joyce (1995) presented these same scales of reference, but implicitly added a further smaller scale, that of an individual site, such as a road cutting.

Scale was more formally addressed in a series of classification papers on coastal and wetland landforms by Semeniuk and co-workers (Semeniuk 1986a; C A Semeniuk 1987; Semeniuk *et al* 1989). The landforms in these works were described in frames of reference of fixed sizes, using terms for frames of reference such as regional, large, medium, small, and fine (Semeniuk 1986a; Semeniuk *et al.* 1989), or megascale, macroscale, mesoscale, microscale, and leptoscale (C A Semeniuk 1987). These frames of reference (modified after Semeniuk 1986a), can be used to describe sites of geoheritage significance (Table 2).

Table 2

Definition of the various scales of reference, with examples

Scale term	Frame of reference	Examples
Regional scale	100 km x 100 km or larger	mountain range scale or drainage basin scale: Dampier Archipelago complex
Large scale	10 km x 10 km	large outcrop scale: limestone barrier at Port Hedland
Medium scale	1 km x 1 km	small mesas and adjoining plain
Small scale	10–100 m x 10–100 m	outcrop scale: such as local cliff face exposure
Fine scale	1 m x 1 m	bedding scale: such as fossils in a shelly lens
Very fine scale	1 mm x 1 mm, or smaller	crystal features

A selection of various scales of geological and geomorphological phenomena is presented in Table 3, graded to illustrate the range of scales, and the variety of phenomena that occur at these different scales that need to be addressed in assessing sites of geoheritage significance. The range of scale encompassed by geoheritage is conceptually illustrated in Figure 2.

The matter of significance

Significance in geoheritage and geoconservation is the assigning of a value to a natural geological or geomorphological feature. The Oxford Dictionary defines the word significance as the quality of being worthy of attention (Simpson & Weiner 1989).

While significance is noted in many works dealing with geoconservation, the various levels of significance, *i.e.*, international, national, State-wide, regional, to local, has not been adequately addressed or defined. Significance at international and national level particularly has not been adequately dealt with globally, in part probably as a result of a historical accident relating to what constitutes international and national where many European countries are national entities and yet fall within the scale of intra-national if viewed at a continental scale *i.e.*, if they were included within the State of Western Australia (see discussion later). Levels of significance is a matter that needs to be addressed in classification and site selection, and be incorporated into any planning and management strategy so that geoconservation can be addressed in local and regional

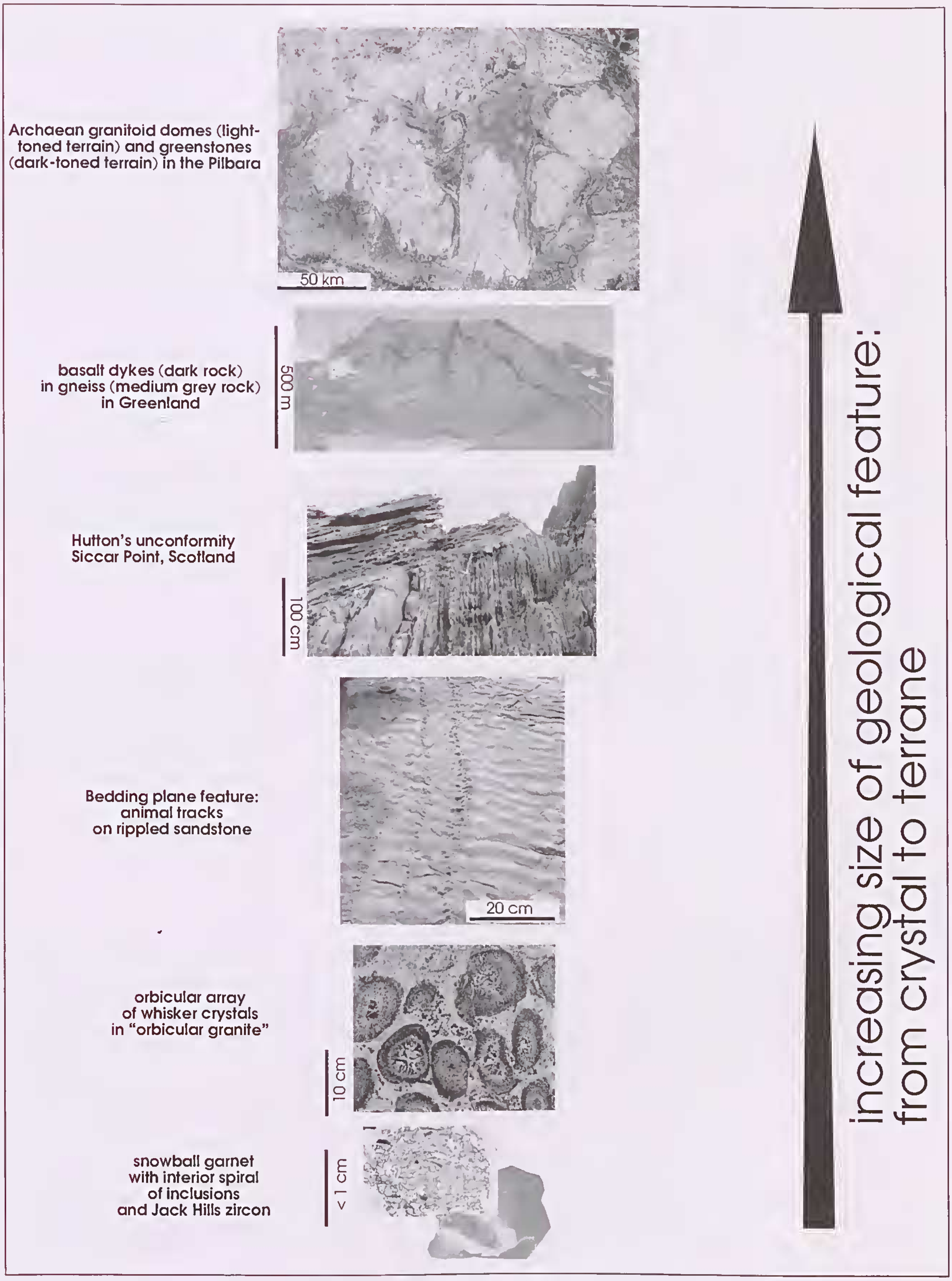

Figure 2. The range of scale of geoheritage features, ranging from crystals, to outcrops, to cliff faces, and terranes.

Table 3

Examples of geological phenomena at different scales

Mountain range scale or drainage basin scale
The Grand Canyon (Holmes 1966), geomorphologically illustrating an entrenched river meander cutting down to a new base-level, pacing uplift of a plateau, and geologically illustrating unconformities, and a sequence from Precambrian into the Palaeozoic
Archaean craton structure, folded greenstones, and Proterozoic dykes in the Pilbara Craton (Hickman 1980; Griffin 1990), geologically illustrating a complex array of rounded intrusive granitoids rimmed by greenstones, and cross-cut by a variety of younger dykes
Linear dune fields from the Great sandy Desert (Veevers & Wells 1961), geomorphologically illustrating a complex variety of dune forms in this desert from straight linear, to branched, to tuning fork
Large outcrop scale
Hutton's unconformity, at Jedburgh (Hutton 1795, cited in Dean 1992), a classic location showing the cycle of deposition, induration, upheaval, planation, and further deposition in the Earth's crust
Lapworth's mylonite, along the Moine Thrust (Lapworth 1885; T A Semeniuk 2003), a classic location first used to illustrate the milling of rocks along a major fault
Interlayered black basalt dykes and granitic gneiss, East Greenland (in Myers 1997), the result of the initial rifting between North America and Europe
Bedding scale
Dinosaur footprints in the Broome Sandstone at Gantheaume Point near Broome (Geological Survey of Western Australia 1975), illustrating dinosaurs ambulating across tidal flats in the Mesozoic
Precambrian Ediacara fauna from South Australia (Glaessner 1966), illustrating the oldest invertebrate fauna in the world
Cambrian fauna from the Burgess Shale in Canada (Gould 1989), illustrating a unique, complex and diverse fauna in Cambrian times
Crystal scale
Snowball garnets of Vatterbotten, Sweden (Barker 1998), illustrating rotation under shear of crystals and their spiralling incorporation of surrounding layered matrix
Orbicular structures of the Thorr Granodiorite of Donegal, Ireland (Pitcher 1993) illustrating concentric whisker crystal formation under delicate conditions of growth, diffusion and cooling
Zircons from Jack Hills in Western Australia (Wilde *et al.* 2001), so far, the oldest crystals in the world, showing the Earth was already solid 50 million years after its formation

issues, as well as the axiomatic protection of sites of international and national importance.

The level of importance attributed to a given feature of geoheritage significance is related to one of two factors: 1. how frequent, or common, is the feature within a scale of reference; and 2. how important is the feature intrinsically or culturally.

In the first instance, if a given geological feature is common at the local scale, and is similarly common everywhere throughout the region, and everywhere throughout the nation, and occurs generally everywhere throughout the globe, then that feature is not significant locally, regionally, nationally or globally. Calcite crystals cementing dune sand are an example of such a feature, and their occurrence throughout an area, locally, regionally, nationally, and globally is not significant. Similarly, but on a larger scale, aeolian cross lamination in Pleistocene calcarenite, such as in the coastal zone of the Swan Coastal Plain and the offshore limestone islands, southwestern Australia (Fairbridge 1950; Semeniuk & Johnson 1985; Playford 1988) is another example: this feature is common throughout many areas (McKee & Ward 1983), locally, regionally, nationally, and globally, and hence is not significant. If, on the other hand, a geological feature occurs once or infrequently at the local scale, but occurs at that same frequency through the regional, and nationally, and globally, then it is feature significant at the local scale. However, if a geological feature occurs once or a few times within a nation (*e.g.*, inland stromatolites occurring at Lake Clifton, Lake Richmond, Lake Thetis, and some lakes in the Eyre Peninsula in South Australia), then it is of national significance. And if a geological feature occurs only once, or a few times world-wide (the tidal flat stromatolites of Shark bay, and the zircon crystals of Jack Hills), then it is a feature of global significance. These notions are summarised diagrammatically in Figure 3.

The examples in Figure 3A illustrate a range of geological features both at different levels of significance and at various scales. The geological features used to illustrate examples of international significance are the large scale features of the Grand Canyon, El Capitan in the Guadalupe Mountains, sinter mounds at Pamukkale, Turkey, an emerged salt dome in the Zagros Mountains in Iran, and the Shark Bay coastal and marine system in Western Australia, and a small scale feature, *viz.*, a Precambrian fossil (from the Ediacara fauna) from the Rawnsley Quartzite in South Australia.

The Grand Canyon, a Global Heritage site, illustrates geomorphic and stratigraphic features, as mentioned earlier in the text (Holmes 1966; Shelton 1966). El Capitan is a well exposed outcrop of Permian limestones that, within the Guadalupe Mountains in Texas, USA, illustrate a shelf margin carbonate complex with transitions from shelf margin to restricted shallow subtidal to supratidal shelf interior (King 1948; Matthews 1984); it is part of the Guadalupe Mountains National Park, and was designated as a World Heritage site in 1990 (Anon 1990b) in part on the basis of its geological features. The sinter mound, in Turkey, at Pamukkale (Cotton Palace, so named because of the calcite deposits, deriving from hot springs, that form spectacular formations), is large deposit of calcite, with some 200 m relief, formed from carbonate-enriched spring waters that have precipitated and constructed an unusual mineral landscape (Dilsiz 2002). It was inscribed as a Global Heritage in 1988 (Anon 1988). The salt dome set in a folded belt in the Zagros Mountains, southwestern Iran, is part of a suite of features that occur in the tectonically active region of the Middle East that include folding, faulting, thrusting, and diapirism. While salt domes are occur sporadically around the world (*e.g.*, the USA, Mexico, the North Sea, Germany, Romania, and the Middle East), the dome in the Zagros Mountains is unusual in that it is a large scale example set in a region that hosts one of the most prolific fold-and-thrust belts in the world, formed by the collision between the Eurasian and Arabian tectonic plates (Sherkati & Letouzey 2004; Letouzey *et al.* 1995). Also, elsewhere in the world, salt domes result in anticlinal doming, but remain in the subsurface. In the Zagros Mountains, the salt dome illustrated in Figure 3A is emergent amid a system of anticlines and synclines. Shark Bay, in Western Australia (Logan & Cebulski 1970; Playford 1990), was placed on the World Heritage list in 1991 because of its globally unique marine and terrestrial environments, and its geology, geomorphology, and carbonate sedimentology. As mentioned earlier, it is one of the places in the world that satisfy all four natural criteria for listing. For Shark Bay, evident in Figure 3A is the central NW-trending Peron Peninsula, flanked to the east by a massive submarine seagrass-vegetated and constructed barrier (the Faure Sill), and to the southwest, portion of Edel Land, with its cliffed western shore cut into Tamala Limestone, and its digitate eastern shore composed of marine inundated limestone terrain of lithified parabolic dunes (Logan *et al.* 1970). The fossil locations preserving the Precambrian Ediacara fauna illustrate features of global significance at a bedding scale. The fossil illustrated in Figure 3A is *Tribrachidium heraldicum*, an unusual disk-shaped organism with triradial symmetry. Uluru, in the Northern Territory is a large inselberg (see below) which has been inscribed as a World Heritage site for its natural history and cultural values. It is globally, and nationally unique, because of its size and shape, combined with its composition. It is considered to be the largest inselberg in the world, and unlike many that are erosionally developed from cratons, and composed of granite and/or gneiss, Uluru is composed of vertically dipping bedded feldspathic sandstone.

Figure 3B illustrates the notion of national significance by using inselbergs and intra-continental volcanic landscapes erosionally derived from Cainozoic volcanoes.

Inselbergs (also termed bornhardts, and by some authors, monadnocks) are geomorphic features: they isolated large hills, knobs, ridges, or small mountains that rise abruptly from a gently sloping or virtually level surrounding plain (Twidale 1968a; Bates & Jackson 1987). Inselbergs are relatively common, occurring in many parts of the world, and Figure 3B illustrates the occurrence of some well-documented and notable ones (though this map is only indicative and does not show their occurrences exhaustively). Inselbergs are underlain by granite, gneiss, sandstone, conglomerate, and a variety of other rock types, though uniformly weathering hard rocks, such as granite and gneiss, preferentially form domed inselbergs. In this context, arid Australia, Western Australia, and South Australia host quite a number of inselbergs (*e.g.*, in Western Australia: Boorabbin National Park, Hyden, The Humps, Mount Augustus; Twidale 2000, Twidale & Bourne 2004), often composed of granite or gneiss, where softer overlying sedimentary or saprolitic materials have been weathered and eroded away to expose unweathered core of bedrock. In a series of papers, Twidale and colleagues have described the morphology, origin, complexities, and small scale features of inselbergs, or bornhardts (Twidale 1968a, 1968b, 1968c, 1986, 2000, Twidale & Campbell 1984; Twidale & Bourne 2003a, 2003b, 2004; Twidale *et al.* 2002). Their research showed that the topographic forms are complex, with several structural domes, that the rock masses may be in compression along one axis and hence with differential water penetration and consequences in weathering rates, that sheet fractures are tectonic features, and that the rock masses continue to be stressed so that neotectonic forms are still developing (Twidale & Bourne 2003a). Twidale *et al.* (*op cit*) explained much of the large scale to small scale features of inselbergs: from general overall morphology, to flaring, concavity, fluting, rilling, to A-tents, amongst others. Their research results are important in a context of geoconservation because they underscore the need to identify and preserve, in what superficially appears as a simple landform, the wide range of processes and products that are associated with inselbergs in a variety of lithologic, structural, chronologic, and climatic settings.

Wave Rock, which is part of Hyden Rock, near Hyden in Western Australia (Twidale 1968c), and Murphy's Haystacks on the Eyre Peninsula, South Australia (Twidale & Campbell 1984; Twidale 1986) are used to illustrate nationally significant landforms in that they illustrate site-specific features of erosion of granite domes and development of smaller scale landforms and morphology. Wave Rock illustrates a well developed

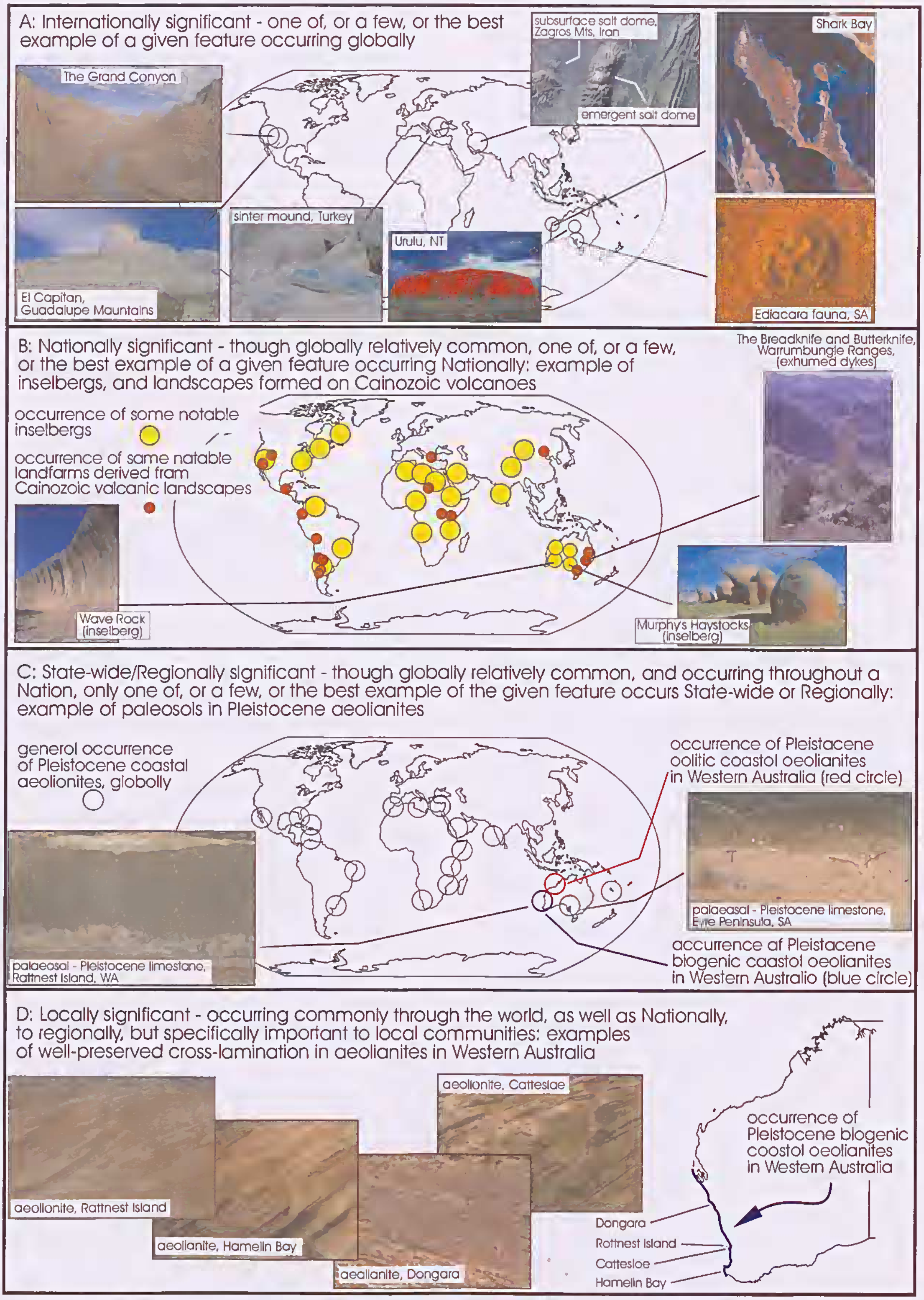

Figure 3. Diagrammatic representation of the levels of significance applicable to geoheritage features. A: International; B: National; C: State-wide to regional; and D: Local. Note that for Pleistocene aeolianites in Western Australia, coastal north-western oolite-dominated types are separated from coastal south-western biogenic-dominated types. The regionally significant palaeosols occur within biogenic-dominated aeolianites in south-western and southern Australia.

over-steepened basal slope (or concave overhang, or flared slope), that is one of the best developed of such features in Australia. Murphy's Haystacks is an unusually shaped cluster large granite boulders and pillars standing near the crest of a broad domical hill, and exhibits tafoni and flares (Twidale & Campbell 1984). Being in a near-coastal location, Murphy's Haystacks, unlike granitic inselbergs elsewhere in inland Australia, has a stratigraphic contact with Pleistocene calcrete, which enables a chronology to be determined for its surface. Both Wave Rock and Murphy's Haystacks have been nominated as geological monunment heritage sites by the Geological Society of Australia (Carter 1987; Anon 2003; Anon 2004b).

Volcanoes and volcanic terrains also are common globally, with the best developed volcanic systems situated around the "Pacific ring of fire" (Sutherland 1995; Murphy & Nance 1998). However, for the purposes of illustrating nationally significant geomorphic features, we concentrate on intra-continental volcanic landscapes erosionally developed, or remnant from Cainozoic volcanic activity (as distinct from volcanic landscapes that are wholly extant, or landscapes eroded from pre-Cainozoic volcanic sequences, *e.g.*, exhumed Palaeozoic or Mesozoic volcanic sequences, or volcanic systems in island arc settings). Figure 3B illustrates the occurrence of some well-documented and notable Cainozoic volcanic landscapes (though, again, this map does not show their occurrences exhaustively). Volcanic landscapes are underlain by a variety of volcanogenic materials and rock types, and are in various stages of erosion, *e.g.*, from intact cones, to eroded landforms with exhumed plugs and dykes (Cas & Wright 1988; McPhie *et al.* 1995). In Australia, Cainozoic volcanism resulted in a series of eruptions stretching from Queensland to Tasmania, temporally staged, as the Australian Plate migrated over a (stationary) mantle hotspot (Sutherland 1995). At present, these volcanic systems of differing ages (younging southwards) reside in various climates, such that weathering and erosion has resulted in differential degrees of preservation of original volcanic forms and exhumation of plugs and dykes. In the Warrumbungle Ranges, in New South Wales, for instance, the landscape cut into the Cainozoic volcanogenic materials, has variably eroded the original cones, and exhumed plugs and dykes (Wilkinson 1969; Faulks 1969). The Breadknife and Butterknife, shown in Figure 3B, with a backdrop of jagged peaks that are partly exhumed plugs, illustrates the landforms of exhumed erosionally more resistant dykes (the Breadknife and the Butterknife) that had intruded the general volcanic setting, and now stand out in spectacular relief.

Palaeosols (fossil soils; Bates & Jackson 1987) in Pleistocene aeolianites are selected as the geological feature to illustrate the notion of State-wide to regional significance (Fig. 3C). Aeolianites are common around the world, as described by McKee & Ward (1983) and Bird & Schwartz (1985), but while aeolianites are common, palaeosols within them are less well developed, by nature of the fact that they represent hiatus intervals, and that they stand little chance of preservation in a dominantly (aeolian) erosive environment. Their occurrence within an aeolianite sequence therefore is of some significance. In Figure 3C, for Western Australia, two types of aeolianites are distinguished: a southern subtropical suite dominated by biogenic calcarenites (Playford *et al.* 1976; Semeniuk & Johnson 1985; Playford 1988; Semeniuk 1995), and a northwestern tropical suite dominated by oolitic limestone (Semeniuk 1996). Within the subtropical biogenic calcarenite suite, constituting the coastal limestones along southwestern Australia, palaeosols have been described by Fairbridge (1950), Fairbridge & Teichert (1953), and Playford (1988). In South Australia, within the Bridgewater Formation, they have recorded by Belperio (1995). Palaeosols frequently contain land fossil snails. Their localised stratigraphic occurrence and negligible thickness relative to the volumetric abundance of aeolianites, signals soil formation in the coastal aeolian environment, thus is of State-wide to regional significance because of their palaeo-environmental and palaeo-ecological implications.

Cross-lamination is used as an example of a locally significant feature (Fig 3D). Given the globally widespread occurrence of aeolianites, as cited above, there also is abundant reference to, and documentation of aeolian cross-stratification therein (Fairbridge 1950, Fairbridge & Teichert 1953; McKee & Ward 1983; Semeniuk & Johnson 1985; Playford 1988; Belperio 1995). Cross-lamination in aeolianites thus is a common feature, and not of global, national, or even regional significance. It would, however, be of significance to a local community, or teaching institutions if there were well preserved examples of the structure in a given area to be used for cultural or teaching purposes. Figure 3D illustrates some examples of well preserved cross-lamination in Pleistocene aeolianites from a number of locations spanning the north-to-south extent of the biogenic aeolianite suite in south western Western Australia.

In the second instance, a geological feature may assume global significance because it is a cultural site of significance. Even if the geological feature is perhaps common throughout the world, the location of its first description may become a site of geoheritage significance for two reasons: it provides a type site of what is meant by the description provided by the first researcher, and secondly it may represent a location of scientific historical interest. Lapworth's mylonite site along the Moine Thrust at Knockan Crag in Scotland (Lapworth 1885; T A Semeniuk 2003) is an example of such a location. Thrust zones, and their associated mylonites, are common around the globe, but the Moine Thrust at Knockan Crag provides a specific historical location wherein Lapworth (1885) first reconstructed the dynamic metamorphic processes of milling of rocks to form finely laminated fault rocks (the mylonites). It is a site where researchers can visit and revisit to test the definition, refine or redefine terms, and calibrate their notion of fault rocks, and it is a site of scientific historical (cultural) significance. Conserving sites of scientific historical significance is the equivalent to enshrining, as culturally significant, the site of the metaphorical or actual apple tree (if it still existed) that, as legend would have it, provided Sir Isaac Newton with the idea of gravity (Keesing 1998; National Trust 2006).

A number of authors have attempted to address the matter of significance in relation to geoheritage and geoconservation (Dixon 1996, Sharples 2002, Joyce 1995, Semeniuk & Semeniuk 2001). Joyce (1995) discusses the use of the term significance in assessing geological heritage. Dictionary definitions are provided for the inter-related terms significance, outstanding, and representative, significance for instance being the "meaning or import of something, importance, consequence". Joyce (1995) suggests that sites of geoheritage significance can lie on a scale between highly significant to of little or no significance. However, Joyce (1995) does not provide examples of what is considered as significant in geoconservation, and there is no grading of significant.

The Australian Heritage Commission (1990), similarly, set out criteria to assess sites that are significant enough to be placed on the Register of the National Estate, but there are several deficiencies: for instance, there is no explanation of what is considered to be significant (*i.e.*, the criteria are broadly worded, and there is no yardstick or comparative measure with wording such as "the geological site must be a unique feature in Australia to be considered as highly significant" to enable readers to positively identify sites of significance); there are no comparative examples of significance, nor grading of significance from "highly significant" to moderately significant" to "of low significance", and no reference base to review and compare the attributes of sites already in the conservation estate with sites to be added or in some cases replaced with better examples. Later, the Australian Heritage Commission (Cairnes 1998) dealt with significance, identifying it as the process of assessing the importance of a site. The Australian Heritage Commission (1990) identified *types* of heritage significance (*viz.*, natural, indigenous, and historic cultural), providing criteria of significance (*e.g.*, cultural phases and the evolution of ecosystems; rarity; research, teaching; representativeness; amongst others, as found in the *Australian Heritage Commission Act 1975*) which can be individually graded 1–10, and outlining how "statements of significance" could be prepared.

Kiernan (1990) discussed use of the term significance in relationship to geomorphology, proposing that significance be addressed from a number of perspectives: why is a landform significant? to whom is it significant? at what scale is it significant? and is its significance likely to be temporary or permanent? Kiernan (1990) suggests that two principal approaches can be taken with regard to significance: either landforms are outstanding examples, or representative examples. However, Kiernan (1990) also emphasises that while it is important to protect outstanding examples of particular landforms, it is likely to result in neglect of the more common types, which in time also will become rare.

From the literature it is clear that while many authors identify significance as a factor in assessment (*e.g.*, Joyce & King 1980; Davey & White 1986; Dixon & Pemberton 1991; Joyce 1995; Sharples 2002; and the Australian Heritage Commission 1990, 1998), and some set up criteria to assess whether a geological or a geomorphological site is significant, the approach in the early phases taken by these authors appears to be one of an of "either/or" situation, *i.e.*, either a given site qualifies to be significant or it doesn't. Later, when the term significance was more rigorously explored (Kiernan 1990; Australian Heritage Commission 1998; Sharples 2002), criteria for grading and allocation of levels of significance still were not defined. The assessment of significance remained a subjective process.

Semeniuk (1986b) and Semeniuk & Semeniuk (1987, 2001) directly addressed the issue of significance in their work on the conservation of mangrove coasts, inland wetlands, and sites of geoheritage importance on the Swan Coastal Plain, respectively, by developing a practical tool in providing scales of significance and criteria for their recognition. Their work, in principle, is applicable to assessing sites of geoheritage significance in general, and in providing grades of "significance". Significance can be ranked according to levels or degrees. Amalgamating these works (*op cit.,)*, we recognise 5 levels of significance:

International,
National,
State-wide,
Regional, and
Local.

Sharples (2002), summarising work by Rosengren (1984) and others, has presented a similar grading, but added a category of unknown significance where insufficient information is available to make an assessment.

While the levels of significance listed above have been used globally, nationally in Australia, and within Western Australia, there generally is not a definition of these terms, except by the Semeniuk and Sharples references cited above. An expansion of the definition of these terms, based on Semeniuk (1986b), Semeniuk & Semeniuk (1987, 1991, 2001), Sharples (2002) and Hogan & Thorsell (2005), with examples of natural features globally, nationally and within Western Australia (Geological Survey of Western Australia 1975; Australian Heritage Commission 2005, UNESCO 2002, according to these levels of significance are presented in Table 4.

In the context of the levels of significance discussed above, we return to Figure 1 to provide a measure of assessment of the geoheritage significance of these features.

Cape Range is a large scale geological and geomorphic feature of international significance (Fig. 1A). It illustrates a coastal landscape developed by Cainozoic tectonism (generating a barrier-and-gulf coastal form along the interface between the Carnarvon Basin and the coastal plain of the Pilbara Coast; Semeniuk 1993), with subsequent drainage superimposed on a limestone terrain. It also illustrates terracing due to progressive uplift of various Pleistocene marine sediments and coral reefs (van de Graaff *et al.* 1976). And it contains a karst system that is a habitat to stygofauna. Its geological characteristics have been recognised as contributing to its values as a National Park (Conservation & Land Management 2005). Recently, it was proposed as part of a World Heritage listing by the Department of Environment & Conservation (World Heritage Consultative Committee 2004).

The linear dune field in the Great Sandy Desert (Veevers & Wells 1961) is a desert geomorphic feature of aeolian landforms (Fig. 1B). They are the dominant linear dune field in the State. From a national perspective, linear dunes are present through Australia (King 1956;

Table 4

Definitions and examples of levels of significance for sites of geoheritage significance[1] (note that the size of these features of geoheritage significance ranges from the very large scale (e.g. The Everglades) to crystals (Jack Hills zircons)

Significance	Definition	Examples	Rationale
International	only one, or a few, or the best example of a given feature occurring globally, hence it is globally unique, rare, or uncommon; or performs a function in a global network	1. Everglades, Florida, USA; 2. carbonate deposits, Roebuck Bay, WA 3. sinter and springs, Pamukkale, Turkey 4. tidal flat columnar stromatolites, Shark Bay; WA 5. Jack Hills zircons, WA	Globally unique systems or geological features
National	while it may be present elsewhere globally, only one, or a few, or the best example of a given feature occurring nationally; hence it is Nationally unique, rare, or uncommon; or performs a function in a National network	1. Permian/Precambrian unconformity, Halletts Cove, SA 2. volcanic landforms, Warrumbungle Ranges, NSW 3. Murphy's Haystacks, Eyre Peninsula, SA 4. Wave Rock, near Hyden, WA 5. the Pinnacles at Cervantes, WA	unique systems or geological features within a given Nation, or performs a function in a National network
State-wide	while it may be present elsewhere globally or nationally, only one, or a few, or the best example of a given feature occurring State-wide; hence in the State it is rare, or uncommon; or performs a function in a sub-national network	1. karst features in southern Western Australia 2. Leschenault Peninsula barrier dunes, WA 3. the buttes in the NW Pilbara region, WA 4. Pleistocene rocky shore stratigraphy exposed in limestone cliffs along the Perth coast, WA 5. orbicular granite, Mount Magnet, WA	unique systems or geological features within the State
Regional	while occurring elsewhere globally, nationally, or State-wide, only one, or a few, or the best example of a given feature occurring in the Region; hence it is uncommon or rare in the Region; or performs a function in a regional network	1. Lake Gnangara on the Swan Coastal Plain, WA 2. conglomerate outcrop at Nannup, WA 3. Bunbury Basalt outcrop at Bunbury, WA 4. mesa formations, southwestern Pilbara region, WA 5. specular haematite crystals, Koolyanobbing, WA	important systems or geological features in the Region, and for the coastal limestone, exposure of atypical stratigraphy
Local	the natural history feature is important only to the local community	limestone cliffs along the Perth coast, illustrating well-formed cross-lamination in the limestone	important to the local community and schools

[1] This list is not to imply that the full range of features noted/listed here have been formally recognised as significant. We provide this list, that derives from application of the criteria developed in this paper, as examples of the level of significance that we consider should be attached to the nominated feature.

Jennings 1968), and in terms of continuous extent of area covered, and clarity of development, the dunes in the Great Sandy Desert comprise some one third of the best developed, and beast preserved linear dune fields Australia-wide. The linear dunes in the Great Sandy Desert, however, carry an addition significant feature – they reside in a modern basin (the Canning Basin), and their seaward extremities interface and stratigraphically interact with sediments of the coastal zone, as described by Jennings (1975) and Semeniuk (1982). Additionally, the dune field of the Great Sandy Desert fall into the category of broad crested linear dunes (Wasson *et al.* 1988), and comprise one of the two major concentrations of such dunes in Australia, the other being in the Northern Territory (see figure 5 of Wasson *et al.* 1988). These aspects render them as geomorphic features of State-wide significance.

The recurved spit of small shells (the Hamelin Coquina; Logan *et al.* 1970) illustrates a coastal geomorphic and stratigraphic feature of global significance (Fig. 1C). Shell accumulations peripheral to hypersaline basins are unusual globally, and prograded coastal plains formed by such shell accumulations shell are equally unusual. As part of the Shark Bay World Heritage site, the lithologic, stratigraphic, and diagenetic history of the Hamelin Coquina (Logan 1974) itself serves as a globally unique and significant classroom in sedimentology, stratigraphy and diagenesis.

The buttes in the north-western Pilbara, illustrate geomorphic and geologic features (Fig. 1D). The buttes are developed from the hard capping of Mesozoic sedimentary rock that unconformably rests on Precambrian granite, effectively highlighting the stratigraphic interface between sedimentary deposits of the Canning Basin and the Precambrian rocks of the Pilbara Craton. This unconformity is located *circa* 30 m above sealevel, and the ensemble of geological and geomorphic features renders these buttes as of State-wide significance.

The Pinnacles at Cervantes illustrate a geological and geomorphic feature of National significance (Fig. 1E). While limestone, calcreted pipes, and yellow sand cover are common along the coastal fringe of south-western Australia, the occurrence of exhumed calcreted pipes to form an extensive pinnacle landscape is unique in Western Australia. Further, the landscape is not developed along the eastern board of Australia, and also not developed in South Australia, where age-equivalent and lithologically equivalent coastal limestones occur. This makes the pinnacles a feature of national significance.

The folded laminated ironstone and chert, developed along a decollement in the rocks of the Brockman Iron Formation in Hamersley Gorge, Karijini, in the Pilbara region is a feature of regional significance (Fig. 1F). It is a well exposed example of such a fold, and is useful to structural geologists to assist in reconstructing the tectonic history of the Hamersley Group. The exposure in the gorge also provides access to contacts, whereas outcrops of such decollements and their associated folds are not so well exposed throughout the region.

Similarly, the outcrop of Bunbury Basalt at Bunbury (Fig. 1G) provides exposure of a valley fill of this Cretaceous basalt, where normally it remains largely buried under the Leederville Formation (Playford *et al.* 1976). While there are more extensive and larger outcrops of this basalt along the southern coast of Western Australia, the outcrop along the coast at Bunbury illustrates the narrow outcrop of a valley form body extending to the northwest. In terms of geomorphology, the outcrop of the basalt at Bunbury is low in elevation relative to sealevel, and shows coastal geomorphic features of basalt subject to coastal erosion and weathering resulting in shore platforms and specific microtopography. The outcrop at Bunbury is also the type location of the formation, and as such is a site of geoheritage significance.

The folded metamorphic rock, in the Owingup area, illustrates isoclinally folded gneissic amphibolite (Fig. 1H). As a structural and metamorphic feature it is locally significant in that it a well developed example of this type of folding and rock type exposed along the coast by marine erosion and marine weathering, and it can assist structural geologists in reconstruction metamorphic and structural history along the south coast of Western Australia.

The scale at which a given geological feature is assessed as significant should not imply that all features at that site at other scales of reference are of equal importance. For instance, the landforms in the Jack Hills area are not of international, national, or State-wide significance, but the zircon crystals therein are internationally significant. Conversely, the inselberg at Uluru and the fact that this large landform is composed of vertically dipping feldspathic sandstone is of international significance, but the individual feldspar grains comprising the sandstone are not significant, as feldspathic sandstone is common globally, nationally and State-wide.

Discussion and Conclusions

The main conclusions of this paper in relation to the scope of geoheritage, in terms of its conceptual categories, the scale of geological features that need to discussed, and the levels of significance of terranes, cliffs, outcrops and crystals that need to be applied are summarised in Figure 4. The four categories of sites of geoheritage significance are very different in their scope. The first involves type examples, or reference sites or locations, and these were some of the first recorded and preserved sites of geoheritage significance, and addressed type stratigraphic and soil locations, type fossil locations, and geomorphic locations as standards for Earth scientists for research and education. Culturally significant sites were those where geological principles were first explored and explained – Hutton's unconformity site is a typical and classic example. Geohistorical sites are those where former Earth processes and Earth history can be inferred and reconstructed from outcrops such as cliffs – the Grand Canyon serves as an example of this category in that it exhibits a classic stratigraphic sequence and geomorphology to enable reconstruction of Earth history. The last category relates to modern landscapes where actives processes are operating – these provide information about extant Earth processes *per se*, and also are useful for interpreting ancient sequences.

The scale of a site of geoheritage significance illustrated in Figure 4 intends to convey the notion that the importance of a geological feature may be at the terrane scale (in this diagrammatic example, we use a large scale igneous intrusion, and its metamorphic aureole as the principle of a large scale feature), but can range down to the cliff, bedding or rock scale, and ultimately to the crystal aggregate and individual crystal. These matters are important because we consider that the full gamut of scale in geoconservation, to date, has not been systematically addressed, as in many geological reconstructions of Earth history the analysis may begin at the crystal scale (*cf.* Logan 1974; Hobbs *et al* 1976; Barker 1998), but also can encompass larger frames of reference (using structural and metamorphic examples for the concept of the employment of increasing scale, see Turner & Weiss 1963, Hobbs *et al* 1976; Wilson 1982; Nicholas 1987; Davis & Reynolds 1996; and Barker 1998).

Finally, regardless of the size of the geological phenomenon being considered, be it terrane-scale, outcrop or bed scale, or crystal scale, the significance of the geological feature whether it is international, national, State/regional, or local in importance needs rigorous criteria for assessment. This aspect applies equally to features of geology such as igneous, metamorphic, sedimentary, or structural terranes and their crystals, as well as to geomorphic features such as distinct mountain ranges, smaller scale mesas and buttes, down to variable microtopographic features on, say, a salt-weathered rocky shores cut into specific rock types.

The remainder of this discussion is broadly framed around three aspects: 1. why the arena of geoconservation should be expanded to include all aspects of Geology, 2. the story of geology that Western Australia has to tell, and 3. how the concepts, terms and yardsticks of measurement presented in this paper are applicable to existing conventions and agreements to which Australia is a signatory.

In the first instance, given the lack of conservation-oriented geologists in government agencies and non-government bodies, one of the main thrusts of this paper was to raise the scientific consciousness as to what is formally encompassed by the notion of Geology for those practitioners of natural systems conservation who are outside the field of geology, and also to raise the consciousness of Western Australian scientists, planners and land managers to matters dealing with geoheritage and geoconservation.

While the full discipline of what constitutes geology is

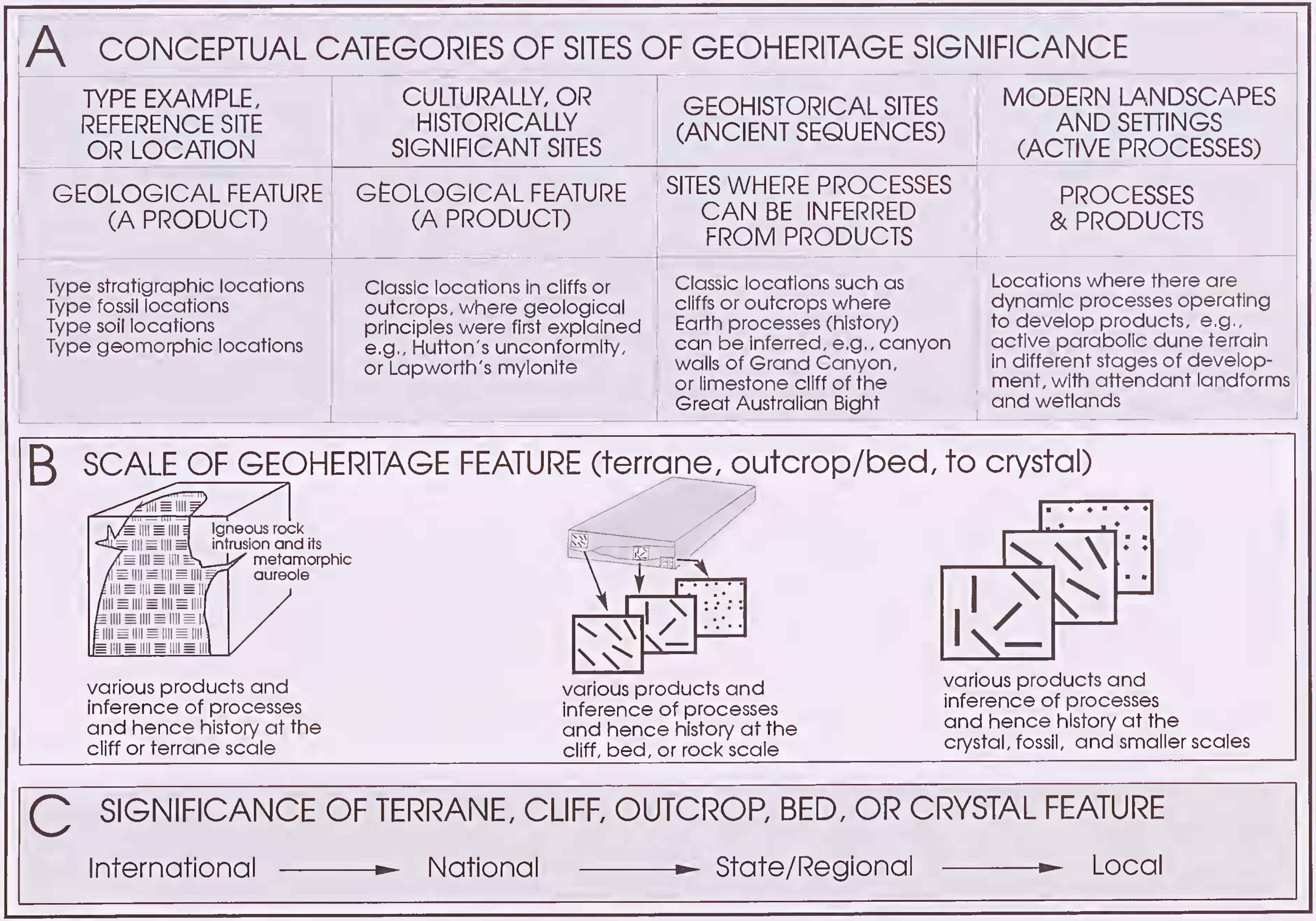

Figure 4. Summary diagram showing the scope of geoheritage in terms of its conceptual categories, its scales of application, and potential levels of significance.

clearly spelt out in texts and dictionaries, the gamut of this discipline had not been fully addressed in geoconservation. Further, geoconservation should address all scales of geology, from the mountain to the crystal. This also is a matter that had not been fully addressed in current geoconservation.

The United Kingdom and Europe have many globally unique locations and sites that classically portray the history of the Earth, locations where concepts of Earth processes and products were first described, and sites that are part of our Western Philosophy and Scientific History (and as such, essentially are outdoor Museums of cultural and scientific history). However, Western Australia itself has its own geological story to tell (Brocx 2007). It offers remarkable, unique, and different geological and geomorphological features of global importance – the Shark Bay stromatolites, the Jack Hills zircon crystals, the mound springs of the Great Sandy Desert, amongst many others. In many locations, Australia has provided global examples of geological features (*e.g.*, the Ediacara fauna in South Australia), or global type sections illustrating geological phenomena (e.g., the limestone rocky shores of Point Peron at Rockingham, is the classic site where Fairbridge 1950 developed the standard eustatic sea-level curve for an oscillating post-glacial rising sea). A range of features of geoheritage significance in Western Australia are shown in Figure 3. For this reason, Western Australia can offer sites of special significance to the global network of geoconservation.

In keeping with global objectives for geoconservation, and in order to comply with Australia's international responsibilities under the World Heritage Convention (Appendix 1), and other international agreements involving the idea of environmentally sustainable development and the precautionary principle, a inventory-based systematic classification of the State's geoheritage is required. Some of this has been undertaken by Carter (1987) and Lemmon *et al* (1979), and others, but it has not been a State Government endeavour, and the results of Carter (1987) and Lemmon *et al* (1979) have not been formally adopted by the State's conservation agencies. In order to meet the objectives of geoconservation, clearly defined policies with a whole-of-government approach is required with public policies that define the role of each government agency in conserving sites of geoheritage. In addition, clearly defined public policies are required to define the role of government in balancing resource development with conservation. In this context, this paper provides definitions, terms, approaches of scale, and approaches of significance to more rigorously achieve these objectives.

It is important to note that State Agreements with the Commonwealth provide the legislative framework for geoconservation at the national to local level with inter government and interdisciplinary approaches (Beeton *et al.* 2006; Johnston 2006). It is important also to note that embedded in them are the principles involving inventory-based classifications. Overseas, similar agreements have used an inventory based classification system to stock-take sites of geoheritage significance for the appropriate level of conservation and management. As such there is a basis to apply the same principles and methods in Western Australia. This approach has been used successfully for the protection of biodiversity and wetlands, for example, and is the basis for recommendations and nominations for sites of geoheritage significance. However, Australia, and particularly Western Australia, still lag behind in the systematic methodology and inventory-based assessment being undertaken as a unified international approach to geoconservation in the United Kingdom and Europe (Brocx 2007).

Geoconservation will only progress forward with education, the formation of community interest groups, and a sea change in the misperception that geoconservation leads to a loss of employment for geologists and loss of revenue to the State. From the literature it is apparent that educational initiatives in geoconservation are fundamental to raising the consciousness to the importance of geoheritage. Typical geoconservation programs include both public, and primary, secondary and tertiary education initiatives in schools, museums, and higher education institutions. In addition, geoparks are an established alternative to resource exploitation in their use for education, economic and social benefits. This is because geological phenomena are basic components of the natural environment and therefore contribute strongly to the development of society. The primary reference-points for geological theory have been, and always will be, the landscape, the rocks themselves and their weathering products. Accessible sites in good condition are essential for the training of geologists and students that need to access some aspects of geology. Such sites represent valued and irreplaceable standards, which should be protected against the pressures of urban, industrial and rural development" (Lemmon *et al* 1979). The importance of environmental education in the global context is summarized in the 1997 UNESCO Statement titled – Educating for a Sustainable Future: A transdisciplinary vision for concerted action (Anon 1999b).

In Western Australia, the main task of geological education of the public rests with the Western Australian Museum, who have assembled an important and impressive publicly viewable collection of minerals, rocks, meteorites, and fossils (in a display termed "From diamonds to dinosaurs"), and periodically inform the public of interesting features of geological interest (*e.g.*, stromatolites, the Pinnacles, meteorite craters, amongst others: Bevan 1992; Bevan & McNamara 1993; Bevan & Downes 2000; McNamara 1997, 2002). In this context, it is also worthy to note the attempt in the 1990s by the National Trust of Western Australia to introduce geoheritage into the secondary school education curriculum failed. Nonetheless, education of students, politicians, decision-makers, and the public on matters geological, to bring them to an appreciation of the richness of our geological heritage remains as an important objective for future geoconservation.

Aside from discussing the evolution and use of definitions used in geoconservation, and outlining the historical development of geoheritage and geoconservation, our main objectives in this paper were to define geoheritage captured under the umbrella of geology (Table 1) as a basis to identifying sites of geoheritage, conceptualise the various categories of what constitutes geoheritage (Fig. 4), deal with the issue of scale in identifying sites of geoheritage significance (Fig. 2), and more rigorously define levels of significance that might be applied to assessing sites of geoheritage significance (Fig. 3). We consider that these outcomes are essential foundations to designing classification and assessment systems to identify sites of geoheritage significance in Western Australia, as a prelude to compiling an inventory of sites of significance as a basis for more systematic geoconservation.

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Appendix 1

Chronological list of Legislation, Acts, State Agreements, and Conventions referred to in this paper

World Heritage Act (1972; UNESCO)

Australian Heritage Commission Act 1975 (Commonwealth)

The *World Heritage and Properties Act 1983* (Commonwealth)

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act; Commonwealth)

Bilateral agreement to deliver the Natural Heritage Trust extension between the Commonwealth of Australia and the State of Western Australia. Agreement dated 17th December 2002

Memorandum Of Understanding Between The Government Of Australia and The United Nations Educational, Scientific And Cultural Organization On Cooperation Concerning The Protection And Promotion Of World Cultural And Natural Heritage In The Asia-Pacific Region. Signed at Melbourne, Australia, on the seventh day of May, 2002 (Commonwealth)

Australian Heritage Council Act 2003 (Commonwealth)

Heritage Amendment Act 2003 Environment and Heritage Legislation Amendment Act (No 1) 2003.

The *Environment and Heritage Legislation Amendment Act (No. 1) 2005,* (Heritage Act; Commonwealth)

Appendix 2

Definitions and history of the use of geoheritage, geoconservation, geodiversity, and related terms

Term	Definition, or usage, and/or history of the term
Geoheritage, and the related terms geological heritage, geoheritage site	
geoheritage (Bradbury 1993)	first use of term "geoheritage" in *A preliminary geoheritage inventory of the eastern Tasmanian terrane*. "Geoheritage is here taken to mean those aspects of the Earth which are important to our understanding of Earth history. The nature of geoheritage sites, which are akin to cultural heritage sites or documents, means that they are non-renewable resources."
geoheritage (Dixon 1996)	"those components of natural geodiversity which are of significant value to humans for purposes which do not decrease their intrinsic or ecological values; such purposes may include scientific research, education, aesthetics and inspiration, cultural development and contribution to the sense of place experienced by human communities; this use of the term is synonymous with Earth Heritage as defined by Stevens (1994) and Wilson R C L (1994); this definition of geoheritage used by World Heritage 2005 (Dingwall *et al.* 2005)
geoheritage (Sullivan 1997)	"those components of geodiversity that are important to humans for purposes other than resource exploitation; things we would wish to retain for present and future generations" (proposed by Sullivan as the definition, deriving from the Australian Heritage Commission workshops, for use by the Australian Heritage Commission)
geoheritage (Semeniuk 1997)	"nationally significant features of geology, including igneous, metamorphic, sedimentary, structural, palaeontologic, geomorphic, pedologic or hydrologic attributes that offer important information or insight into the formation or development of the continent, or that can be used for research, teaching or as a reference site."
geoheritage (Semeniuk 1998; Semeniuk & Semeniuk 2001; Anon 2006)	"Statewide to Nationally important features of geology, including igneous, metamorphic, sedimentary, structural, geochemical, palaeontologic, geomorphic, pedologic or hydrologic attributes that offer important information or insight into the formation or evolution of the continent; or that can be used for research, teaching or reference sites."
geoheritage (Osborne 2000)	"geoheritage consists of all the significant Earth features and continuing processes that we wish to keep, sustain, conserve, manage and interpret for their natural heritage value"
geoheritage (Komoo 2000)	"geoheritage value is strongly linked to scientific value [...] in terms of scientific records for research and education. However, some of them, particularly mineral, fossil and unique landform features, can also be associated with aesthetic, recreational or cultural values".
geoheritage site (Cook *et al.* 1998)	"...sites of geoheritage significance identifies areas principally under the following (National Estate) categories: A: Its importance to the course or pattern of Australian natural history. B: Its possession of uncommon, rare or endangered aspects of Australia's natural history. C: Its potential to yield information that will contribute to an understanding of Australia's natural history. D: Its importance in demonstrating the principle characteristics of a class of Australia's natural history, or a class of Australia's natural or cultural environments. E: Its important in exhibiting particular aesthetic characteristics values by a community or cultural grouping"
geoheritage (Anon 1999a; Anon 2000)	"those components of geodiversity that are important to humans for purposes other than destructive exploitation; things we would wish to retain for present and future generations"
geoheritage (Sharples 2002)	anthropocentric or (geo)heritage values, *i.e.*, anthropocentric reasons for valuing particular elements of geodiversity; "those elements of natural geodiversity which are of *significant* value to humans for non depleting purposes which do not decrease their intrinsic or ecological values"
geoheritage (Gray *et al.* 2004)	"comprises concrete examples of geodiversity which may be specifically identified as having conservation significance"
geoheritage (Conservation & Land Management 2005)	"State-wide to nationally significant features of geology, including igneous, metamorphic, sedimentary, structural, palaeontologic, geomorphic,, pedologic, or hydrologic attributes that offer important information or insights into the formation or evolution of the continent, or that can be used for research, teaching or as a reference site"
geological heritage (Anon 1991; JNCC 1994)	used as the title of the first conference for geological conservation: "First International Symposium on the Conservation of our Geological Heritage" which took place in Digne, France. "More than 120 specialists from over 30 nations conducted for the first time a world-wide review of the conservation of this heritage. They unanimously endorsed the declaration of the rights of the Memory of the Earth ..."

Term	Definition, or usage, and/or history of the term
geological heritage (Joyce 1997)	"might be defined as: those geological features of value, whether as representative of a group, or outstanding (unusual or rare) consisting of: • natural landforms and landscapes (including ancient landforms and landscapes); • Earth materials (including rocks, minerals, fossils, soils and regolith, and water, including groundwater), • evidence of geological processes (both internal and external, and past and present), • evidence of geological time (including the definition of specific geological stages or time periods using such features as rock sequences, unconformities and weathering profiles, fossils and dating techniques), found at or near the Earth's surface, in natural outcrop or artificial exposures, and available to be observed, appreciated, enjoyed, studied or used for education". Joyce (1997) suggested here that "geological heritage" is a more appropriate term to use when discussing the heritage and conservation aspects of Earth science phenomena
geological heritage (Zagorchev & Nakov 1998; Gonggrijp 1999; Brilha 2002)	related to the "importance of the site (locally, regionally, nationally, and internationally), and its use (educational, scientific, and recreational), and the need to conserve it".
geological heritage (McBriar 1995)	"encompasses the diversity of minerals, rocks and fossils, and also the features that indicate their origin and alteration through time. It includes landforms and other geomorphological features which illustrate the effects of present, and past, exposure to climate and Earth forces"
Geoconservation and Geological Conservation	
geoconservation (Legge & King 1992)	"protection of significant geological and landscape features because of their scientific, educational, research, aesthetic and inspirational value to humans"
Earth Heritage conservation (Stevens 1994)	"Earth heritage conservation is concerned with the part of the physical resources of the Earth that represents our cultural heritage, recognizing that that means both the scientific side of it and the inspirational side of it."
geological conservation (Stevens 1994)	"Geological conservation is strongly linked to other cultural conservation areas: it is concerned with conserving the means of intellectual development, as opposed to economic conservation.... Geological conservation is particularly concerned with two aspects of the use of Earth science heritage: our geological understanding including the means to advance it in the future, and the aesthetic value of the heritage."
geoconservation (Dixon 1996)	"The conservation of geodiversity for its intrinsic, ecological and (geo)heritage values. These values can be defined as follows: Intrinsic value -the concept that a thing is of value in itself, rather than only because of a purpose for which it might be used by humans or by other living species; Ecological value - the importance of a thing or process in maintaining natural ecosystems and ecological processes of which it is a part."
Geodiversity conservation (Kozlowski 1999)	"working out the notion and rules of protecting geodiversity of inanimate nature...; evaluation and assessment of geodiversity in the fields of geology, pedology and surface and ground waters; presentation of the structure of Polish landscapes in relation to geodiversity preservation; development of geoconservation network; preparation of a draft inventory .....; setting up information system about geodiversity; preparing information booklets and cartographic leaflets...".
geoconservation (Sullivan 1997)	"the identification and conservation of geological, geomorphological and soil features, assemblages, systems and processes (geodiversity) for their intrinsic, ecological or heritage values"; (proposed by Sullivan as the definition, deriving from the Australian Heritage Commission workshops, for use by the Australian Heritage Commission)
Geoconservation Kiernan (1997)	"Geoconservation is about the employment of land management strategies to safeguard geoscientific phenomena"
geoconservation (Semeniuk 1997; Semeniuk 1998; Semeniuk & Semeniuk 2001)	"conservation of Earth science features (geological, geomorphological, pedological, and hydrological) that are of sufficient significance to warrant preservation for purposes of heritage, science, or education."
geoconservation (Sharples 2002)	"the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values"
geoconservation (Anon 2000)	"the identification and protective management of geological, geomorphological and soil features, assemblages, systems and processes (geodiversity) for their intrinsic, ecological or heritage values"

Term	Definition, or usage, and/or history of the term
geoconservation (Dixon 1996; Dingwall *et al* 2005)	"the conservation of geodiversity for its intrinsic ecological and heritage values"
geoconservation (Prosser 2002a)	"geological and geomorphological conservation"
geoconservation (Prosser 2002b)	"a term widely used internationally, and a sensible synonym for geological/geomorphological conservation"
geoconservation (Sharples 2002)	"aims to preserve the natural diversity – or 'geodiversity' – of significant geological (bedrock), geomorphological (landform) and soil features and processes, *and to maintain natural rates and magnitudes of change in those features and processes*" (emphasis added) "… geoconservation does not focus solely on the importance of non-living things in conserving biological systems, but is also based on the premise that geodiversity has important conservation values of its own, independent (*sic*) of any role in sustaining living things" Sharples notes that Earth features are commonly not robust, and therefore in need of conservation, and gives several examples of features that are not robust, such as "delicate fossils or rare mineral sites are easily destroyed by inappropriate excavations… Ongoing landforming processes … can easily be degraded by inappropriate disturbances in their water catchment areas"
Geoconservation (Gray *et al.* 2004)	"the endeavour of trying to conserve geodiversity and geoheritage" (after Sharples 2002)
Geodiversity	
Geodiversity Australian Heritage Commission 1996) 1.8	"means the range of Earth features including geological, geomorphological, palaeontological, soil, hydrological and atmospheric features, systems and *earth processes*"
geodiversity- (Joyce 1997)	"A new term recently suggested for use when discussing geological heritage activities." "the possible use of the term was suggested…and discussed at the 1993 international conference at Malvern UK but failed to receive significant support…" "the term appears to have been developed in an attempt to draw parallels with the widely-used term biodiversity." However, " … the heritage significance of a geological site, landform or region may in some cases lie not in its diversity but in its uniformity"
geodiversity (Sharples 1993)	"diversity of Earth features and systems"
geodiversity (Sharples 1995; Komoo 2000; Sharples 2002)	"the range (or diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes"
geodiversity (Dixon 1996)	"the range or diversity of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes"
geodiversity (Australian Heritage Commission 1996)	"the range of Earth features including geological, geomorphological, palaeontological, soil, hydrological and atmospheric features, systems and Earth processes"
geodiversity (Sullivan 1997; Anon 2000)	"the natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes; geodiversity includes evidence for the history of the Earth (evidence of past life, ecosystems and environments) and a range of processes (biological, hydrological and atmospheric) currently acting on rocks, landforms and soils." (proposed by Sullivan as the definition, deriving from the Australian Heritage Commission workshops, for use by the Australian Heritage Commission)
geodiversity (Eberhard 1997)	"The relationship between 'geodiversity', 'geoheritage' and 'geoconservation' can be summarised thus: geodiversity is an *objective quality* of the natural environment; geoheritage is made up of *examples* of aspects of geodiversity that have been identified as having conservation significance; and geoconservation is the *endeavour* of trying to conserve geodiversity"
geodiversity (Semeniuk 1997; Semeniuk 1998)	"the natural variety of geological, geomorphological, pedological, hydrological features of a given area, encompassing the purely static features (*i.e.*, products such as shoreline sandy spits, or limestone pinnacles, or river canyons) at one extreme, to the assemblage of products and their formative processes at the other (*e.g.*, active parabolic dunes forming under a given wind regime)."

Term	Definition, or usage, and/or history of the term
geodiversity (Sharples 1995; Dixon 1996; Kiernan 1995, 1997; Household *et al* 1997)	"The range or diversity of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes"
geodiversity" (Kozlowski 1999)	"differentiation of the Earth as to geological structure, relief, soils, climate, surface and groundwaters combined with demands and impacts of humans".
geodiversity (Johansson *et al.* 2000)	"the complex variation of bedrock, unconsolidated deposits, landforms and processes that forms the landscape….. Geodiversity can be described as the diversity of geological and geomorphological phenomena in a defined area"
geodiversity (Stanley 2000)	"the variety of geological environments, phenomena and active processes that make landscapes, rocks, minerals and other superficial deposits which provide the framework for life on Earth, *i.e.*, the link between people landscapes and their culture through the interaction of biodiversity, soils, minerals, rocks, fossils, active processes, and the built environment."
geodiversity (Anon 1999a; Anon 2000; Australian Heritage Commission 2003, 2005; Dingwall *et al* 2005)	"the natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes. Geodiversity includes evidence of the past life, ecosystems and environments in the history of the Earth as well as a range of atmospheric, hydrological and biological processes currently acting on rocks, landforms and soils."
geodiversity (Gray 2004)	"Geodiversity: the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems."
geodiversity (Wong *et al* 2001)	"suggests a parallel with biodiversity and that the term geodiversity was possibly adopted for that reason"
geodiversity (Prosser 2002a)	"the variety of rocks, fossils, minerals and natural processes"
geodiversity (Prosser 2002b)	"the variety of rocks, fossils, minerals and natural processes. However, it is now being used by some in a very holistic way to emphasise the links between geology, people and wildlife. It is suggested that this may a synonym for Earth heritage conservation"
geodiversity (Stace & Larwood 2006)	"the link between rock, landscape, soil, biodiversity and the processes that maintain the natural functions of our environment. It provides many of our resources and defines our surrounding environment"
Geodiversity (Gray *et al.* 2004)	"the topography, structure and natural form of the land: the natural range of soil, geomorphological and geological features. It includes their assemblages, relationships, properties, interpretations and systems (after Gray, 2004)
geodiversity *versus* geotopes (Vincent 2004)	"geodiversity is difficult to measure, therefore it is better to "think in terms of geotopes… Geotopes are spatially defined terrestrial units with outstanding geological or geomorphological qualities that are worthy of protection for future generations. Their definition specifically requires that they provide evidence of the geological history of the landscape and its development. Some scientists distinguish between passive and active geotopes, depending on whether a process that has led to its formation is still active or not"
geodiversity unit (Osborne *et al* 1998)	"is defined as: land that exhibits particular and related geodiversity characteristics (e.g., geological/geomorphic history, rocks, landscape, soil, hydrology etc). Areas of land forming a single geodiversity unit will often be discontinuous. While geoheritage units may correspond to traditional geological and geomorphic units, they may also cross tectonic and stratigraphic boundaries"
Geodiversity (Osborne 2000)	"Geodiversity is the whole range of natural Earth features and processes"

Term	Definition, or usage, and/or history of the term
Terms related to geoheritage, geoconservation, geodiversity, and sites of significance (not exhaustive)	
National Estate "place" (Australian Heritage Commission Act 1975)	"those places, being components of the natural environment of Australia or the cultural environment of Australia, that have cultural, aesthetic, historic, scientific or social significance or other special value for future generations as well as for the present community"
heritage value of a "place" (*Environment Protection and Biodiversity Conservation Act 1999*)	as including "natural and cultural environment having aesthetic, historic, scientific or social significance, or other significance, for current and future generations of Australians"
"place" *in*: Natural Heritage Charter 1.1 (Australian Heritage Commission 1996)	a "site or area with associated ecosystems, which are the sum of its geodiversity, biological diversity and natural processes"
natural heritage (World Heritage Convention 1972, see Appendix 1)	operational guidelines include - "geological and physiographical formations and precisely delineated areas constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science, conservation or natural beauty", ...and ..."natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty". The scope of what can be regarded as of "outstanding universal value" is defines as having met one or more of 4 criteria. This includes: "(i) be outstanding examples representing major stages of Earth's history, including record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features"
Earth Heritage (Wilson C 1994; Ellis *et al* 1996; Dingwall *et al.* 2005))	Definition recommended in the report *2005 Geological World Heritage: A global Framework* by Dingwall *et al.* (2005): "the inheritance of rocks, soils and landforms (active and relic) and the evidence they contain that enables the history of the Earth to be unraveled"
Earth Heritage conservation (Doyle *et al.* 1994)	"concerned with sustaining the part of the physical resources of the Earth that represents our cultural heritage, including our geological and geomorphological understanding, and the inspirational and aesthetic response to the resource".
significant geological feature (Legge & King 1992; Dixon 1996; Joyce 1995)	"Those features of special scientific or educational value which form the essential basis of geological education, research and reference. These features are considered by the geological community to be worthy of protection and preservation"
significant geological features (Legge & King 1992)	"Significant geological features (SGF) are those features of special scientific or educational value which form the essential basis of geological education, research and reference. These features are considered by the geological community to be worthy of protection and preservation"
significant geological features (Geological Society of Australia 2006)	"significant geological features – (SGF) are those features of special scientific or educational value which form the basis of geological education, research and reference. These features are considered by the geological community to be worthy of protection"
geological site (Rienks *et al.* 1984)	"geological sites are defined as 'geological features which are of such geological or physiographic significance that they warrant preservation for the future' and justifying protection on one or more of the grounds of 'teaching of the science', 'scientifically rare, unique or otherwise important' or 'aesthetic, educational or recreational value'
geovalues (Veer 2002)	"Geovalues comprise the geological, geomorphological, geohydrological and pedological objects and processes in a landscape (or parts of it) which are representative of the history of that landscape" (opening statement in the summary)
Earth science conservation (Anon 2000)	"Geological exposures and landforms can be considered as discrete 'sites' which, if their importance warrants it, may be systematically conserved"

Term	Definition, or usage, and/or history of the term
Geological/ geomorphological conservation (Prosser 2002b)	"This is the favoured terminology in English Nature, meaning the conservation of geology and geomorphology in its natural setting"
geological monument (McBriar & Mooney 1977)	"… features considered by the community of Earth scientists to be of such geological or physiographic significance that they are worthy of preservation. When taken together, the geological monuments of the State should adequately represent the geological history of the region "
Geological monument (Joyce 1995)	"Geological monuments are those features of a region which form the essential basis of geological education, research and reference: the total network of geological monuments incorporates the minimum number of sites to adequately represent the Geology and Geomorphology of the region" (definition adopted at the Second Geological Convention held at Monash University in 1977). " 'A geological feature may be a single rock outcrop, a rock sequence in a natural or artificial exposure such as a cliff or road cutting, or more rarely a major landscape such as Gosses Bluff, NT. In some cases a monument may be lookout where the geomorphology of the surrounding district may be viewed' " as described by the Committee for the Preservation of Geological Monuments in the ACT The author notes that the use of the term "geological monument" is now used less commonly than it once was.
Sites of geological significance (Geological Survey of Western Australia cited in Conservation & Land Management 2005)	"geological features of the Earth that are considered to be unique and of outstanding value within Western Australia and to have significant scientific and educational values"…